DOCUMENT RESUME

ED 146 885 IR 004 686

TITLE The Use of the Computer in Teaching Secondary School Subjects.
INSTITUTION Organisation for Economic Cooperation and Development, Paris (France). Centre for Educational Research and Innovation.
PUB DATE 76
NOTE 74p.

EDRS PRICE MF-$0.83 HC-$3.50 Plus Postage.
DESCRIPTORS Biology Instruction; Case Studies; *Computer Oriented Programs; *Computers; Instructional Materials; Physics Instruction; *Research; *Secondary Education; *Simulation
IDENTIFIERS Centre for Educational Research and Innovation

ABSTRACT

This report is based on the work of international research panels and a 1973 workshop on whether, and how, the computer could be used to enhance learning within individual disciplines in the secondary school. Eight recommendations are based on the criterion that the computer should be used in teaching only tasks that either it alone can fulfill, or that it can carry out markedly better than any other resource within economic limitations. Chapters cover these topics: (1) the computer in teaching biology and physics; (2) applications in mathematics, social sciences, business studies, and the humanities; and (3) materials design, guidelines for package documentation, dissemination of materials and information, and teacher education. The recommendations take two approaches: the simulation of cause-effect principles and manipulation of the existing variables by students, and simulation allowing students to deduce relationships under conditions that permit rapid manipulation of variables. Examples of computer-based materials currently available are appended. (Author/KP)

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THE USE OF THE COMPUTER IN TEACHING SECONDARY SCHOOL SUBJECTS

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FOREWORD

Of all recent technological developments, the computer, with its vast storage capacity, its ease of access, and its flexibility of programming has perhaps the greatest potential as a tool for learning. Its earlier disadvantage of a clumsy typewriter terminal is disappearing with the development of reasonably priced 'screen' terminals; its costs decrease steadily - teacher costs rise. Already in higher education it is increasingly used as a supplement to the lecture seminar methods. In secondary education considerable experimental work has now been undertaken : it is with the results of this work that this report is concerned.

At this level, it has been the capacity of the computer to simulate experimental situations that has particularly caught the imagination of those concerned with the natural sciences, with mathematics, and with certain fields in the social sciences. Here students, working within a controlled enquiry process, can devise and test hypotheses from a wide range of simulated experiments which are freed from the problems of inadequate equipment and student inaccuracy on the one hand, and which are too dangerous, too tedious or impossible to provide in a school laboratory situation on the other.

I. METHOD AND GENERAL CONCLUSIONS OF THE INVESTIGATION

1. GENERAL BACKGROUND

By 1968, when CERI was founded, the educational world had passed through several waves of enthusiasm for "new" technologies - television and teaching machines particularly. Each in its turn had been held up as potentially the solution to all problems of teaching and learning : each had proved disappointing. In the late 60's the emphasis switched to computers; again, they were hailed as the possible answer to all educational problems. However, a counter-movement to the over-enthusiastic approach developed and this movement saw the teaching/learning process as a complex interdependent system in which technology might play a part. It became clear that systematic investigation, analogous to but not identical with systems analysis in use in other fields, should be used to determine the role technology could play in any teaching/learning process. Emphasis was put on the economic as well as the pedagogic feasibility of new systems.

From its inception CERI adopted this approach and initially decided that it would examine the possible use of the computer in varying kinds of teaching/learning systems. It was clear that the computer's potentiality was considerable : it could store, and rapidly retrieve, a mass of data; it could be programmed to simulate real situations; the algorithmic logic used in computer programming was itself a valuable mental process for students to undertake. However it was equally clear that, although costs were diminishing, the computer was comparatively expensive as an educational tool.

2. COMPUTER SCIENCE IN SECONDARY EDUCATION

With these considerations in mind CERI developed a two-pronged investigation. The first approach concentrated on the use of the computer as a direct element of the teaching/learning system in higher education where its cost was reasonable in relation to the level of expenditure. The second considered the part it had to play in the secondary school system where initially efforts were concentrated on

what should be taught about computers in the school. This work culminated in the publication "Computer Science in Secondary Education", following an international seminar in Sèvres in 1970. The recommendations of this seminar stressed heavily the value of "computer science" in schools, whether as a separate course or as integrated with normal school subjects and, particularly, the value of the algorithmic approach. Much stress was also put on the need to educate teachers in computer science. One recommendation for further work was to investigate the use of computer science in the learning of individual subjects in the secondary school and it was this that CERI chose to study further.

3. THE USE OF THE COMPUTER IN THE LEARNING OF SECONDARY SCHOOL SUBJECTS

Though initially conceived as "the use of computer science and particularly the algorithmic approach", this programme of investigation rapidly broadened to a more general consideration of whether, and if so how, the computer could be used to enhance learning within individual disciplines in the secondary school. The method chosen was to set up international "panels" of those carrying out research and development in their own countries which would meet regularly to interchange experience and ideas. Originally it was hoped that four panels could be set up, but it only proved possible to organise groups for physics and biology. These however met regularly during late 1971 and 1972 and proved very fruitful. It was then decided to bring their work together with that carried out independently in other subjects in Member countries at an international Workshop in Edinburgh in December 1973. This Workshop was attended by both those actually engaged in research and development and those interested in introducing or furthering it. Seventeen countries sent between them sixty-five participants. The first part of the Workshop was devoted to practical demonstrations and talks on what had so far been achieved; it was possible for participants to use programs at terminals provided and during talks to see on video-screens examples of the programs being discussed. The second part involved discussion by "subject" groups on the state of the art and recommendations for future action within individual disciplines; the final part was concerned with those problems that transcend subject boundaries and recommendations for action in relation to them. This included dissemination and teacher education.

4. THE NATURE OF THIS REPORT

This Report and its recommendations are based on the work of the panels over the past years, on the deliberations of the general working

group on computers and the steering group for the Workshop, and on the discussions which took place at the Workshop itself. Lying behind the recommendations is the criterion that the computer should be used within the teaching/learning system only for tasks that either it alone can fulfil or that it can carry out markedly better than any other resource, all within the limitation of economic possibilities. The latter however is difficult to estimate accurately as costs of computer use are tending to decrease while teacher and other material costs increase. Concentration has been on the possibilities of "simulation and modelling". Some consensus exists that the original emphasis on Computer Assisted Instruction - i.e. the computer as a complex teaching machine - and on drill and practice is at the moment inappropriate at school level, mainly because of costs. However, it is recognised that certain fertile uses in Computer Managed Instruction exist - and one interesting case was brought to the Workshop by Japan - but insufficient consideration was given to it to justify a recommendation in this Report.

The main arguments for the recommendations that follow on the use of the computer in simulation and modelling lie in Chapter II, particularly in the reports on biology and physics. Briefly these are of two kinds. The first is that many situations that embody "cause and effect" principles exist particularly in the physical and biological sciences, mathematics and in certain other subjects such as economics, business studies and geography, and these cannot be experienced practically by students because of difficulty, complexity, or sheer tedium. However, they can be simulated on a computer and thus allow a student to manipulate the existing variables. This can be used either to demonstrate the principle involved or more fruitfully to enable the student to deduce it. The second approach is that simulation should be used to extend practical experience allowing students to deduce relationships under conditions that permit rapid manipulation of the variables.

5. THE MAIN RECOMMENDATIONS

The justification and support for the recommendations made below lie in the ensuing chapters which should be read in conjunction with them still in mind. Since the Sèvres Conference in 1970 much has changed, many lessons have been learned and a great deal of new experience has been accumulated. This resulted in a considerable measure of agreement at the 1973 CERI Edinburgh International Workshop, the substance of which is distilled in the recommendations that follow :

Recommendation 1

The objective of the project has been to examine the potential use of computing that will enhance and enrich the learning process.

From the experience gathered, it has been found that the most fruitful field lies in the computer simulation and modelling of real and hypothetical situations allowing greater student active participation in the learning process.

INVESTIGATION AND DEVELOPMENT OF FURTHER MATERIALS BASED ON SIMULATION AND MODELLING SHOULD BE ENCOURAGED.

Recommendation 2

The computer is being widely used in administration, industry and commerce as a data bank. Despite its potential interest, little use has yet been made of this in education.

FURTHER INVESTIGATION INTO THE EDUCATIONAL APPLICATIONS OF DATA BANKS AND INFORMATION RETRIEVAL AND ANALYSIS SHOULD BE UNDERTAKEN.

Recommendation 3

In order to implement Recommendations 1 and 2 it is necessary for subject teachers to be trained in the educational use of computers so that they can participate in the investigation of the potential of the computer in their own subjects.

TEACHERS SHOULD BE GIVEN THE OPPORTUNITY OF VOLUNTARY SECONDMENT TO FULL TIME COURSES WITH A STRONG WORKSHOP ELEMENT. THE LENGTH OF SUCH COURSES COULD RANGE FROM 1 MONTH TO 1 YEAR DEPENDING ON SUBJECT. HOWEVER, IF THE WORKSHOP IS TO BE EFFECTIVE, 2 - 3 MONTHS WOULD APPEAR TO BE A MINIMUM.

Recommendation 4

Recommendations 1, 2 and 3 will produce many new ideas. A means of disseminating knowledge of these, encouraging their use and providing feedback is required.

ALL TEACHERS AND THOSE TRAINING TO BECOME TEACHERS SHOULD BE PROVIDED WITH AN OPTIONAL COURSE SO THAT THEY CAN USE EXISTING MATERIALS IN THE TEACHING OF THEIR OWN SUBJECTS.

Recommendation 5

The costs associated with all aspects of computing are unavoidably high. A means must be found of minimising development costs, avoiding wasteful duplication of effort and making effective use of materials and ideas thus produced.

THE ESTABLISHMENT OF NATIONAL OR REGIONAL CENTRES SHOULD BE ENCOURAGED FOR THE COLLECTION AND DISSEMINATION OF MATERIAL ORIGINATING AT HOME

AND ABROAD, THE LATTER BEING AVAILABLE THROUGH THE INTERNATIONAL INFORMATION CENTRE FOR COMPUTING IN SECONDARY EDUCATION. (1)

Recommendation 6

Teachers rely upon receiving information about curriculum development through established subject channels. Information about computer-based material may be best conveyed through this mechanism.

ESTABLISHED SUBJECT CHANNELS SHOULD BE USED FOR THE DISSEMINATION OF INFORMATION ON COMPUTER-BASED MATERIALS WITHIN THE VARIOUS SUBJECT DISCIPLINES.

Recommendation 7

The dissemination and classroom use of the materials already referred to will be aided if an agreed content is established and accepted. A package should contain teacher's guide, student's guide and program documentation. There should also be a standard single page description for diffusion of information. Transferability would be aided if there were international collaboration on the use of programming languages.

MATERIALS SHOULD BE AVAILABLE IN A STANDARD FORM.

Recommendation 8

It has been found that the international cooperation achieved by means of panels proves most fruitful. It would be valuable if the established panels could continue to meet annually and if new panels could be set up in other subject areas.

CERI SHOULD SPONSOR THE CONTINUATION OF EXISTING PANELS AND THE SETTING UP OF PANELS IN OTHER SUBJECT AREAS.

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1) The International Information Centre is located at the following adress :
The International Information Centre for Computing in Secondary Education,
Moray House College of Education,
Holyrood Road, Edinburgh, EH8 8AQ. Scotland, United Kingdom.

II. THE COMPUTER IN TEACHING BIOLOGY AND PHYSICS

1. INTRODUCTION

The ensuing chapter concerns itself with the work carried out by the two international panels referred to in section 3 of Chapter I, these being the Biology and Physics Panels. Their common aim was that of considering how the computer could best be used to enhance the learning of their respective subject areas, taking into account both the pedagogical aspects of new systems as well as the economics of the factors involved. Although there is a large measure of similarity in the philosophy adopted by those involved in the work undertaken by the panels, there are differences in attitude which are clearly exemplified in the English and French approaches to simulation and modelling in the field of Physics.

2. THE USE OF THE COMPUTER IN THE TEACHING OF BIOLOGY

Biology contains a great range of subject areas - biochemistry, genetics, behaviour, ecology, etc. - dealing with animals, plants and micro-organisms. There is difficulty in understanding the immense complexity of life at different levels - biophysical, cellular, whole organism, species and, finally, ecosystem.

Biological phenomena are different in kind from many physical phenomena : in physics one measures the effects of enormous populations of molecules; one can seldom investigate a single molecule, atom or particle, except in atomic or nuclear physics. In biology, to understand populations one examines individuals, and statistical techniques must be used to interpret the significance of small numbers. The principles may be simple as in Mendel's Laws but the infinite interactions of many factors make systems of immense complexity. In many of these systems there are feedback mechanisms - some positive, some negative. To investigate these systems we use a very wide range of methods, including mathematical and statistical ones. Nevertheless the teaching of biology has tended to be descriptive. Experiments are usually simple - at least superficially, there being a tendency to choose those experiments that "work" in the classroom situation.

There has been some reluctance among biologists to consider theoretical models, particularly as many have not been easy to test. Where there are many interesting factors, many models can be devised but fewer can be tested. Simple models have also been unpopular, on the assumption that "life cannot be that simple". Certainly where biologists and others have intervened in the world, the results have often been disastrous because the simple models were inadequate (1).

For the teacher, the provision of suitable experiments in biology teaching is often difficult :

1) They may take a long time - Mendel's experiments probably took 12 years.
2) It may be difficult to have an adequate number of animals or plants.
3) In the summer one should be studying ecology which cannot be done in the winter. This may necessitate doing pollution in the winter when the sites may be distant and the weather unsuitable.
4) Experiments are often expensive and also capricious for they may give uninterpretable results.

The computer therefore may be of particular value for the teaching of biology because so many of these difficulties, such as time and cost, can be reduced to tolerable levels. With the computer, we may take the results of real experiments - too difficult or costly to reproduce in the teaching situation - and make a computer simulation. We may formulate the same basic model at various levels of sophistication :

1) A simple relationship producing a single answer, e.g. a straight line graph.
2) The results of several experiments, requiring statistical or sophisticated interpretation.
3) The inclusion of constraints so that a relationship between the factors in the model only operates within certain limits.

Computers are therefore of great potential use for the teaching of many aspects of biology - in some cases providing an alternative or better method than the old, in other cases, widening what could previously be done, enabling new ideas and concepts to be included. There are, however, difficulties. Many biologists, students, teachers and research workers have a limited acquaintance with mathematics and mathematical concepts.

Many have studied biology because they were frightened by figures : the potential use of computers may be frustrated by consumer resistance

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1) See Farvar and Milton, eds. The Careless Technology, Ecology and International Development, T. Stacey, 1973.

and special efforts may be necessary. As the calculations are done by the computer, teaching material can be used by a teacher who would otherwise have difficulty with the teaching of that subject. Because we are dealing with very complicated interdependent systems our models deal only with approximations; computer models that work are correspondingly difficult to produce. That they are worth the trouble of producing, and the cost of their use, has been shown by their trial use in a number of schools.

Computers have had another major effect on biologists. The discipline of writing a program - or even thinking about the possibility of one - has shown many of us new ways of looking at biological problems and conventional explanations. We have long been familiar with the diagram of the life cycle of an animal, but it has not been generally realised that this method of presentation can be full of unsuspected prejudices (1). We have not been sufficiently aware of the potentialities of the flow diagram for biology; there are many areas where it is the obvious method of presentation. It can be used by the teacher or as an exercise by students.

For the biologist, the computer offers a number of possibilities :

a) the removal of the chores of mathematical and statistical computation;
b) the collection, sorting, retrieval and analysis of extensive data;
c) the simulation of experiments that are expensive or otherwise impractical in the classroom;
d) the simulation of experiments by reduction of the time scale.

The first two of these uses are related to general computer employment and do not require special materials or comment. The last two, however, require special materials although not necessarily specialised computer knowledge. From computer projects in biology in Europe and the United States the following rule emerges : subjects for computer simulation should be selected to achieve educational objectives that cannot be more effectively or cheaply taught by other methods. The efforts so far have resulted in a number of self-contained packages, each representing a complete teaching unit (see Appendix for list), designed to supplement existing schemes of study. Each unit consists of a booklet for the teacher giving background teaching material and a computer program. The use of the computer requires a minimal knowledge of computer practice which can be learnt in perhaps 10 minutes' instruction. The programs have been designed for use with a keyboard terminal in the school so that the student may use the computer to enter his own

1) See for instance Red Mites and Typhus by J.R. Andy, Athlone Press, 1968, pages 3-6.

parameters and data for the program in use. Although only a teletype terminal is needed, some of the programs produce graphical displays by the use of spaces and characters (see Figure 3). This interaction of the user with the computer may rouse considerable interest - not only in students but also in teachers. Experience has shown that not the least useful impact has been greater awareness among teachers of the material because the student and teacher booklets contain more detailed (and understandable) information than that found in most student texts. This is partly because the availability of computers has made possible the inclusion of biological material that was not previously considered suitable.

Similarly, discussions about topics suitable for computer simulations have prompted ideas for other ways of teaching the same subject : sometimes it has been a mechanical model, sometimes the use of file cards each containing information, even the use of paper tape to represent DNA, RNA and protein molecules.

To date, the programs have been largely in genetics and ecology : this is partly because these subjects are particularly suitable for computer simulation, partly because a few people have been enthusiastic. In these, the teacher has choice of material and can experiment with more than one teaching unit.

The integration of our individual teaching units, each with its own booklets, tapes, etc., with the curriculum as a whole has not yet been fully explored, nor their integration with other teaching materials : laboratory experiments, programmed learning, films, etc. It is important that this should be investigated, monitored, and the results made available. It would also be interesting to know whether the different techniques that can be used, from simple flow diagrams to complex computer conversations, should be introduced in a linear sequence of increasing complexity.

Because biologists have such diverse backgrounds of training and subject interest and knowledge, because they belong to many specialist societies and because many European countries have no professional society like the Institute of Biology in the UK or the American Institute of Biological Sciences, we are keenly aware of the problems of implementing a programme using computers in the teaching of biology. Already some papers about the use of computers in schools have appeared in the Journal of Biological Education.

A Case Study in Reproduction

One of the most important features that distinguish living organisms from their non-living environment is an ability to reproduce. Birth, growth and death are such fundamental aspects of life that we cannot fail to be aware of them.

Reproduction can be studied both in a single family unit and in a population of individuals. The information necessary for the development and maintenance of an organism must be contained within the structure, such as an egg or a sperm, which passes from one generation to the next, and it must be made available in an orderly sequence so that the organism can grow, and then stop growing as it reaches adult size.

In secondary education many different aspects of reproduction are studied, both theoretically and by practical investigation in the laboratory. This case study describes how computers are helping with one of them - genetics, the science of heredity. Genetical investigations are usually carried out by breeding organisms in controlled environments and following the inheritance of particular characteristics through successive generations. Experiments of this type require large numbers of individuals and sufficient time for several generations to develop. This limits the work that can be carried out in schools, but by choosing an organism which is small, breeds in confined spaces and has a short generation time, effective practical work is possible. Breeding experiments with fruit flies, Drosophila, flour beetles, Tribolium, and other organisms have been included in school biology for many years.

Most of the basic principles of genetics can be investigated with a few carefully selected experiments. Once these have been carried out, second-hand data can be used effectively to extend this knowledge and to show something of the many variations on the basic pattern of inheritance. For studies of this type a computer is unnecessary. Indeed its use could hinder the work by reducing the contact between student and organism that is essential for effective biological study.

However, in order to study the arrangement of heredity factors, or genes, within the nuclei of an organism's cells, many carefully co-ordinated breeding experiments are necessary. Although the pattern of each experiment is the same, all are essential to the successful completion of the investigation. Here a computer can help by simulating a large number of breeding experiments and presenting a student with the results for him to analyse. The simulation described here is called LNKOVR. It was originally developed by Dr. J.L. Crosby of Durham University for undergraduate teaching and has been adapted for use in schools by P. Murphy for the Chelsea Science Simulation Project.

Most organisms are composed of a large number of cells each with a nucleus. When a cell divides, thread-like structures called chromosomes can be seen inside its nucleus. Each species of organism usually has a fixed number of pairs of similar chromosomes, but the number differs from one species to another. The genes are located on the chromosomes and all the genes that are on the same chromosome tend to be inherited together. However, during the formation of the reproductive

cells there is an exchange between adjacent parts of the pairs of similar chromosomes, so that some of the genes are crossed over from one chromosome to the other. The further the genes are away from one another on the chromosome, the greater is the chance of crossing over. Thus, although genes cannot be seen when chromosomes are examined under a microscope, their order and relative distances from one another along the chromosome can be deduced from the frequencies with which they are crossed over.

This computer simulation originally used twelve pairs of genes located on a single chromosome of a hypothetical organism. The mutant gene in each pair is symbolised by a letter and a plus sign is used for the wild type gene of the pair. The student picks three mutant genes which he wishes to cross with the wild type genes. Genes A, C and Y have been chosen in the example given in Figure 1.

The computer then selects at random eggs and sperms containing these genes and their wild type counterparts, brings them together and prints out the characteristics of 200 offspring. Where the three letters or three plus signs are shown together, there has been no crossing over, as with ACY and +++ in the example shown. Mixtures of letters and plus signs, for example A++ and +CY, represent organisms where the genes have been crossed over. The student has to calculate the frequencies with which the genes are crossed over and to determine their arrangement on the chromosome pair. He then chooses another three genes and the process is repeated until he has made a sufficiently accurate map of the genes on the chromosome.

The student was originally asked to classify and count the offspring, since the object was to present him with a realistic situation. If he were to carry out the experiments with real organisms, he would have to do the counting himself. However, experience has shown that this took too much of his time. Consequently, the program has been modified to give the style of print-out shown in Figure 2.

Other changes have also been made. The number of gene pairs has been reduced from twelve to ten and they have been spread further apart along the chromosome. This has enabled the number of offspring per cross to be reduced to 100, thus reducing the time taken to use the simulation.

The computer program is supported by written materials for both student and teacher. The student's notes describe in greater detail than is usual in school textbooks how genetic mapping is carried out, and they could be used independently of a computer. The notes then introduce the student to the simulation and must therefore be read before it is attempted. A class of students can use the simulation together or work in several independent groups, which can be in competition with one another. The initial objective is to find the order of the genes on the chromosome; the distances between them are then

Figure 1

INTERACTION OF MUTANT AND WILD TYPE GENES

```
THERE ARE 12 LINKED GENES WHOSE SYMBOLS ARE A C H I J K M P R T U Y

TYPE SYMBOLS FOR 3 GENES
 ? ACY

F2 PHENOTYPES
-------------

+++     ACY     +CY     +++     A++     ACY     +++     +CY
+CY     ACY     +CY     ACY     ACY     +CY     +CY     ACY
A++     +++     +++     +CY     +++     +CY     ++Y     A++
ACY     A++     +++     ACY     +CY     +++     A++     ++Y
+++     A++     +CY     ACY     A++     +CY     ACY     A++
ACY     A++     A++     AC+     +CY     +CY     +++     +++
ACY     +CY     ++Y     +++     AC+     A++     +CY     +++
+++     A++     +++     +++     ACY     +++     A++     +CY
+++     +CY     +CY     +++     A++     +CY     ACY     A++
+++     +CY     A++     +CY     ACY     +++     +++     +CY
+++     ACY     +C+     A++     ACY     A++     +++     A++
+CY     +++     ++Y     ACY     ACY     +CY     A++     +CY
+CY     +CY     +CY     ACY     +CY     +CY     A+Y     ACY
+C+     +++     +++     ACY     ACY     +++     A++     A++
ACY     +CY     ACY     +++     ACY     +CY     A++     AC+
A++     A++     +++     A++     +C+     +CY     ++      A++
A++     A++     A++     A++     ACY     A++     +CY     +CY
ACY     +++     +CY     +CY     ACY     ACY     ACY     +C+
+C+     ACY     ACY     +++     +CY     A++     +++     A++
+++     ACY     A+      A++     AC+     +++     +CY     +CY
ACY     +++     +CY     A++     +++     A+Y     A++     ACY
+++     +++     +++     ACY     +CY     +++     +++     +CY
++Y     A++     +CY     ACY     A++     A+Y     +CY     ACY
ACY     A+Y     A++     A++     +CY     +CY     +CY     A++
ACY     +++     A++     ACY     A+Y     ACY     +++     ACY

HAPPY COUNTING!


DO YOU WISH TO RE-RUN THIS PROGRAM TYPE 0 FOR NO , 1 FOR YES
 ? 0
```

determined as accurately as possible. When the linkage map has been constructed, it can be compared with the "cytological" map upon which the simulation is based. This leads to a study of other features of gene exchange since, in the simulation as in real organisms, crossing over is less likely near the centromere or the ends of the chromosome and a second crossing over is less likely near the first.

Realism is achieved in this simulation by ensuring that, if any particular cross is repeated, exactly the same frequencies of characteristics amongst the offspring are unlikely. Results that differ from one another when an experiment is repeated are an important feature of

Figure 2

THE RESULTS OF GENE COMBINATIONS SHOWN IN FIGURE 1

```
THE LINKED GENES ARE A C H J K M P R T Y

GENE  1   ? A
GENE  2   ? C
GENE  3   ? H

TESTCROSS
---------

ACH         ACH
---    X    ---
+++         ACH

OFFSPRING PHENOTYPES
--------------------

ACH         21

+++         29

+CH          3

A++          4

AC+          2

+C+         22

A+H          1

-------------

ANOTHER RUN ? YES


THE LINKED GENES ARE A C H J K M P R T Y

GENE  1   ? C
GENE  2   ? T
GENE  3   ? Y

TESTCROSS
---------

CTY         CTY
---    X    ---
+++         CTY

OFFSPRING PHENOTYPES
--------------------

CTY         40

+++         46

++Y          6

CT+          5

+T+          1

C+Y          2

-------------

ANOTHER RUN ? NO
```

biological experiments and are obtained in this simulation by selecting the different genes to be crossed using a random number sequence. Nevertheless the temptation to make the simulation more elaborate has been resisted. Providing for different parental genotypes and numbers of offspring per generation might be useful adaptations for university teaching, but they would hinder the simulation's prime purpose - the teaching of genetic mapping in secondary education.

A Case Study in Ecology

In science education it is generally recognised that learning through direct experience is most desirable. Every curriculum project involves large amounts of time spent in developing laboratory exercises to complement the content of the course. To facilitate student understanding of the scientific approach these new activities have tended to be investigations, rather than simple observational exercises.

This aim, to produce meaningful investigation, makes the subject of ecology particularly difficult to handle in a school laboratory. The area presents several restrictions that often preclude direct experimental experience - for example :

1. Ecological changes most often occur over long periods of time;
2. Sample size is usually restricted in a biology classroom, while ecology tends to deal with organisms on a population level;
3. Many ecology investigations call for equipment not generally available in a secondary school;
4. Experimental techniques are frequently too difficult for the student to handle;
5. Ecological studies normally call for large data bases, not readily organised by the student;
6. The physical environment necessary for a "real investigation" is often not available to the student.

In such situations, biology courses have tended to resort to additional readings or lectures to supplement the learning in the normal classroom. The term "dry lab" has been used in the United States to describe this kind of activity, and the "dry lab" is generally felt to be less effective because students' experience is much less direct.

The computer is an educational tool that may overcome many of the constraints and provide an investigational tool when the "real investigation" cannot be brought into the classroom. Computers have been used for a decade to organise large amounts of data and their ability to free the user from involved and repetitive calculation gives them great strength in dealing with complex systems, as in ecology. Compression of time is another possibility when using a computer. An event that would take place over years can be modelled in a few minutes using an appropriate computer model.

The advantages brought by the computer to ecology can best be illustrated by reviewing two ecology programs currently in use within the United States.

a) POLUT - Water Pollution Study

Pollution studies often require chemical techniques and time periods not available in a survey biology course. By using a computer program a student is able to investigate the effects of human waste on dissolved oxygen content and organic waste levels in a body of water, all without complex procedure or calculation. A period of several weeks may be modelled within a few minutes. The sample print-out (Figure 3) is a portion of an investigation of the role of sewage treatment in eliminating pollution.

b) USPOP - Human Population Study

Human population studies present several problems in the classroom. Clearly actual experimentation is not possible, and the alternative of mathematical analysis is difficult as large amounts of data and complex calculations are necessary. Through the use of a computer the student can carry out this difficult procedure with a few simple instructions.

Figure 4 represents part of a student investigation of fertility's effect on the size and age distribution of population in the year 2000. Any time he chooses a "standard rate" the computer extracts appropriate information on current conditions stored within the program.

Adoption of computers for investigational activities will prove to be a valuable addition to existing educational strategies. Their advantages are especially attractive for topics with many constraints upon actual student investigation.

A Case Study in Nutrition

One of the characteristics of living organisms is the continuing requirement for an input of food. In the case of simple organisms the specific requirements to be met by a diet are not very critical, but higher animals cannot synthesise certain complex body tissue products from simple inorganic compounds. In such circumstances elaborated compounds must be supplied in the diet.

Studies of nutrition in mammals are mainly concerned with the input of carbohydrates, proteins and fats, which are supplied in various proportions by foodstuffs. Their method is to observe the effect of various inputs on the behaviour of organisms, including growth effect, and hence to deduce nutritional requirements. These requirements vary according to the size of the organism, and the activities engaged in, for example height, weight, sex, age and body temperature all affect

Figure 3

THE POLLUTION OF WATER BY HUMAN WASTE

```
INSTRUCTIONS (1=YES, 0=NO) ? 1


IN THIS STUDY YOU CAN SPECIFY THE FOLLOWING CHARACTERISTICS:

A. THE KIND OF BODY OF WATER:
   1. LARGE POND
   2. LARGE LAKE
   3. SLOW-MOVING RIVER
   4. FAST-MOVING RIVER

B. THE WATER TEMPERATURE IN DEGREES FAHRENHEIT:

C. THE KIND OF WASTE DUMPED INTO THE WATER:
   1. INDUSTRIAL
   2. SEWAGE

D. THE RATE OF DUMPING OF WASTE, IN PARTS PER MILLION (PPM)/DAY.

E. THE TYPE OF TREATMENT OF THE WASTE:
   0. NONE
   1. PRIMARY (SEDIMENTATION OR PASSAGE THROUGH FINE
               SCREENS TO REMOVE GROSS SOLIDS)
   2. SECONDARY (SAND FILTERS OR THE ACTIVATED SLUDGE
                 METHOD TO REMOVE DISSOLVED AND COLLOIDAL
                 ORGANIC MATTER)

***********

BODY OF WATER ? 3
WATER TEMPERATURE ? 45
KIND OF WASTE ? 2
DUMPING RATE ? 12
TYPE OF TREATMENT ? 0

DO YOU WANT: A GRAPH(1), A TABLE(2), OR BOTH(3) ? 1


AFTER DAY 2  THE FISH BEGIN TO DIE, BECAUSE
THE OXYGEN CONTENT OF THE WATER DROPPED BELOW 5 PPM.


      0...OXYGEN-SCALE....5...OXYGEN-SCALE...10...OXYGEN-SCALE...15
      0..WASTE.10..SCALE.20..WASTE.30..SCALE.40..WASTE.50..SCALE.60
DAY   I---------I---------I---------I---------I---------I---------I
 0    I   W                                                   O
 1    I             W                          O
 2    I                 W       O
 3    I                   X
 4    I               O   W
 5    I             O     W
 6    I             O      W
 7    I           O        W
 8    I           O        W
 9    I           O        W
10    I           O        W
11    I           O        W

THE WASTE CONTENT AND OXYGEN CONTENT WILL REMAIN AT
THESE LEVELS UNTIL ONE OF THE VARIABLES CHANGES.


ANOTHER RUN (1=YES, 0=NO) ? 0
```

Figure 4

FERTILITY RATES AND POPULATION FORECASTS

```
DO YOU WANT REPORTS 1) EVERY 5 YEAR INTERVAL
OR 2) SELECTED YEARS ? 2

YEAR AT START OF PROJECTION ? 1970

DO YOU ASSUME STANDARD FERTILITY (1=YES,0=NO) ? 0
FERTILITY IN 1970  ? 3.0
WILL FERTILITY (1) STAY AT 3  OR (2) CHANGE SLOWLY
TO A NEW LEVEL ? 1

DO YOU ASSUME STANDARD BIRTH DISTRIBUTION (1=YES,0=NO) ? 1

DO YOU ASSUME STANDARD SEX RATIO (1=YES,0=NO) ? 1

DO YOU ASSUME STANDARD MORTALITY (1=YES,0=NO) ? 1

DO YOU ASSUME STANDARD POPULATION (1=YES,0=NO) ? 1

REPORT:1)SHORT 2)LONG 3)GRAPH 4)CHANGE ASSUMPTIONS 5)END ? 1

YEAR 1970     POP=  204.8  MILLION        FERTILITY 3
YEAR FOR NEXT REPORT ? 2000

REPORT: ? 3

YEAR 2000     POP=  309.7  MILLION        FERTILITY 3
                        PCT. TOTAL POP.
          0.........5.........10........15.......20
 0 - 4    .                    *
 5 - 9    .                   *
 10 - 14  .                   *
 15 - 19  .                   *
 20 - 24  .                  *
 25 - 29  .                *
 30 - 34  .              *
 35 - 39  .               *
 40 - 44  .               *
 45 - 49  .              *
 50 - 54  .            *
 55 - 59  .          *
 60 - 64  .       *
 65 - 69  .     *
 70 - 74  .   *
 75+      .     *
YEAR FOR NEXT REPORT ? 2005

REPORT: ? 5

ANOTHER PROJECTION (1=YES, 0=NO) ? 0
```

them - as do the number of hours of the day spent in these various types of activity. A second aspect of nutritional studies is to prepare diets to meet the needs arising from the circumstances of the organism. The traditional approach to teaching these subjects has been to present tables and graphs of nutritional requirements, and to give examples of the value of selected foodstuffs. Little involvement on the part of the pupil is possible in view of the extensive calculation involved and the fact that the nutritional tables of requirements have but a small chance of covering the needs of whoever happens to be chosen by the pupils as the object of study.

The availability of computers allows a new approach to be developed, using data about pupils and their own diets as an aid to understanding nutritional problems. The extensive calculations they can carry out on a large set of stored data enables a high degree of involvement to be achieved. The package that deals with this is called NUTRIT (see Appendix).

The main objective of this package is to enable the pupil to find the nutritional requirement of a specific person and to observe the effect of changing activity patterns on this requirement. This may be followed by the comparison of any diet with the requirement. The computer's role is that of carrying out the extensive and tedious calculation needed to obtain these objectives.

The package is based on a simple model of dietary needs mainly concerned with the calorific requirement and the energy content of foodstuffs. There is also a simple apportioning of the calorie requirement to be met from carbohydrate, fat and protein sources. Figures 5 - 9 illustrate a typical session with the program.

In the first segment of the program a pupil creates a description of the person to be studied by answering questions 1 to 6. From this description the daily basal metabolism is calculated - a range being indicated to demonstrate the typical variability (see Figure 5).

The second segment of the program (see Figure 6) incorporates the day's pattern of activity and in response to the questions asked the total daily requirement is printed out.

At this point options are available in the program so that the requirement of different people or for different activities may be compared. (See Figure 7).

One of these options (option 4) enables a diet to be constructed from a wide range of foodstuffs listed in the pupil's booklet which is part of his teaching package. An example of the usage of this option is shown in Figure 8.

If the pupil now wishes, he can make modifications to the diet as illustrated in Figure 9.

Figure 5

CALCULATION OF BASAL METABOLISM

```
GIVE IN ORDER
                1.HEIGHT IN METRES
                2.WEIGHT IN KGS
                3.AGE
                4.SEX (1 FOR A MAN. 2 FOR A WOMAN)
                5.BODY TEMPERATURE
                6.ALTITUDE IN METRES
 ? 1.6 ? 65 ? 32 ? 1 ? 37.5 ? 100

                          PARAMETERS
                          1- HEIGHT : 1.6 METRES
                          2- WEIGHT : 65 KGS
                          3- AGE : 32 YEARS
                          4- SEX : MALE (1)
                          5- BODY TEMPERATURE : 37.5 DEGREES
                          6- ALTITUDE : 100 METRES

****************************************
 1370 <= BASAL METABOLISM <= 1520
****************************************
```

Figure 6

DIETARY REQUIREMENTS

```
ACTIVITIES = H1:SEDENTARY LIFE; H2:LIGHT EXERCISE;
H3:SUSTAINED EXERCISE; H4:STRENUOUS EFFORT; H5:VIOLENT EFFORT

 ? 8 ? 8 ? 2 ? 2 ? 4 ? 2 ? 0
IS THE PERSON IN TRAINING ? 1

ACTIVITIES :          8 HOURS OF SLEEP
                      8 HOURS OF SEDENTARY LIFE
                      2 HOURS OF LIGHT EXERCISE
                      4 HOURS OF SUSTAINED EXERCISE
                      2 HOURS OF STRENUOUS EFFORT
                      0 HOURS OF VIOLENT EFFORT

      ************************************************************
      ** BM(CAL) ** CR(CAL) ** CAR (G) ** FAT (G) ** PRO (G) **
      **MIN / MAX**MIN / MAX**MIN / MAX**MIN / MAX**MIN / MAX**
      ************************************************************
      ** 1370    ** 2610    ** 331     ** 101     ** 74      **
      ** 1520    ** 3080    ** 390     ** 119     ** 88      **
      ************************************************************
```

Figure 7

EXERCISES IN ACTIVITY ON FIGURES 5 AND 6

```
YOU HAVE THE CHOICE BETWEEN
     0. IF YOU WANT TO STOP
     1. TAKE A NEW PERSON
     2. CHANGE ONE OF THE PARAMETERS
     3. CHANGE THE ACTIVITIES
     4. MAKE UP THE 24H FOOD RATION
 ? 3

YOU HAVE CHOSEN OPTION  3

DO YOU FIRST WANT TO CHANGE ANY PARAMETERS
 ? 1
GIVE IN ORDER
                1.HEIGHT IN METRES
                2.WEIGHT IN KGS
                3.AGE
                4.SEX (1 FOR A MAN. 2 FOR A WOMAN)
                5.BODY TEMPERATURE
                6.ALTITUDE IN METRES
 ? 1.6 ? 65 ? 32 ? 2 ? 37.5 ? 100
IS SHE PREGNANT (VARIABLE 7)
 ? 0
IS SHE BREAST FEEDING (VARIABLE 8)
 ? 0
ACTIVITIES = H1:SEDENTARY LIFE; H2:LIGHT EXERCISE;
H3:SUSTAINED EXERCISE; H4:STRENUOUS EFFORT; H5:VIOLENT EFFORT

 ? 8 ? 2 ? 2 ? 2 ? 2
IS THE PERSON IN TRAINING ? 1
```

A typical use of the package is first to ask the pupils to find out their own nutritional requirements and to see how these vary within a day. Then typical actual diets are compared with the requirements. This can be followed by examining the change of requirement as the person grows up.

Finally the requirements of men in different parts of the world may be compared with the diets available in those countries.

An Application in Biochemistry

In biology computers are coming to be used because experimental work demands so much time and space that it is impossible to perform it in the normal secondary school. In biochemistry we often have the opposite situation : the experiments run so fast, and the available amount of chemicals are so small that it makes real experiments impossible in school conditions.

Biochemistry is by tradition a typical experimental science where even at the most elementary level the actual performance of practical experiment is regarded as a most important activity. However, the

Figure 8

SPECIFIC DIET CALCULATION

```
YOU HAVE THE CHOICE BETWEEN
     0. IF YOU WANT TO STOP
     1. TAKE A NEW PERSON
     2. CHANGE ONE OF THE PARAMETERS
     3. CHANGE THE ACTIVITIES
     4. MAKE UP THE 24H FOOD RATION
 ? 4

YOU HAVE CHOSEN OPTION  4


DO YOU FIRST WANT TO CHANGE ANY OF THE PARAMETERS
 ? 0
REFER TO THE LIST OF FOODS WHICH YOU WILL FIND
IN THE PUPILS BOOKLET, INDICATE THE FOOD RATION
FOR 24H, BY GIVING THE NUMBER OF THE FOOD AND THE NUMBER
OF UNITS (IN GENERAL THE NUMBER OF GRAMMES)
TYPE 999,0 WHEN YOU HAVE FINISHED
 ? 13,100
 ? 9,15
 ? 11,30
 ? 1,220
 ? 17,100
 ? 18,60
 ? 16,100
 ? 26,35
 ? 29,240
 ? 8,125
 ? 999,0
```

SPECIFIC DIET

FOOD	NO.UNIT	APP.CAL	APP.CAR	APP.FAT	APP.PRO
1	220	374	1	22	44
8	125	87	6	5	5
9	15	114	0	12	0
11	30	105	2	7	7
13	100	250	55	1	7
16	100	340	60	1	22
17	100	90	20	0	2
18	60	18	3	0	0
26	35	98	24	0	0
29	240	168	0	0	0
TOTAL		1644	171	48	87

NON-BALANCED DIET; COMPARE IT WITH THE TABLE BELOW

EN(CAL) MIN / MAX	CP(CAL) MIN / MAX	CAR (G) MIN / MAX	FAT (G) MIN / MAX	PRO (G) MIN / MAX
1280	2520	319	97	71
1420	2980	377	115	85

Figure 9

MODIFICATIONS OF SPECIFIC DIET

```
YOU CAN MODIFY YOUR FOOD TABLE BY
-REMOVING FOODS (TYPE THE NUMBER FOLLOWED BY 0)
-CHANGING THE QUANTITIES (TYPE THE NUMBER AND QUANTITY)
-PUTTING IN OTHER FOODS (TYPE THE NUMBER AND QUANTITY)

 ? 13,400
 ? 25,25
 ? 9,100
 ? 999,0
```

SPECIFIC DIET

FOOD	NO.UNIT	APP.CAL	APP.CAR	APP.FAT	APP.PRO
1	220	374	1	22	44
8	125	87	6	5	5
9	100	760	0	85	0
11	30	105	2	7	7
13	400	1000	220	4	28
16	100	340	60	1	22
17	100	90	20	0	2
18	60	18	3	0	0
25	25	100	25	0	0
26	35	98	24	0	0
29	240	168	0	0	0
TOTAL		3140	361	124	108

NON-BALANCED DIET; COMPARE IT WITH THE TABLE BELOW

BM(CAL) MIN / MAX	CR(CAL) MIN / MAX	CAR (G) MIN / MAX	FAT (G) MIN / MAX	PRO (G) MIN / MAX
1280	2520	319	97	71
1420	2980	377	115	85

computer can prove a valuable tool in the teaching of biochemistry. One of the problems in teaching it nowadays is the fact that the sum of our knowledge is so huge that even elementary teaching cannot be performed satisfactorily in advanced courses in secondary education. For instance, experiments necessary to understand reaction kinetics are difficult and often very expensive. A simulated experiment on a computer is very much faster, and, assuming reasonable use, cheaper too.

This could not take the place of a real experiment, but the normal procedure where students perform one experiment and are then told the results of others could be substituted by their carrying out one or two experiments as usual, and then deciding upon some additional ones which they could proceed to "perform" on the "simulator".

The advantage of this technique over the classic method is clear; as in the old way, the student is taught something about a certain reaction, but in addition to this he tries for himself the scientific method of planning an experiment and making deductions from the results. With the overwhelming amount of information that exists today in biochemistry it is more important to teach the student how to follow the pathways of the scientist than to fill his brain with facts.

Two types of program could be used in this kind of work. One wou contain all the known kinetical data on the reaction in question, and, when supplied with the necessary parameters, concentration, temperature, pH, etc., it could produce the experimental results. Such a program could be used even with very small computers. The other is a bigger program with comments on certain experiments, the student being led to the correct investigations by questions from the computer. This demands a larger computer and more advanced programming.

There are two possible sources for kinetical data; first, actual experiments recorded in the scientific literature; secondly the computer itself providing data from a mathematical model.

As an example of the latter, we can refer to the Huntington program "LOCKEY". This deals with the effect of inhibitors on the conversion of acetylcholine to acetic acid by the enzyme acetylcholine-sterase. Both the amount and the nature of the inhibitor can be varied.

The print-out could be as shown in Figure 10 for an experiment without inhibitor and as shown in Figure 11 for an experiment with equimolar concentrations of acetylcholine and prostigmine.

Figure 10

CONVERSION OF ACETYLCHOLINE TO ACETIC ACID (1)

```
AMOUNT OF ACETYLCHOLINE - FROM Ø TO 3 MILLIMOLES ? 2
TYPE OF INHIBITOR - USE CODE FROM Ø TO 5 ? Ø
DATA FORMAT: 1=TABLE, 2=GRAPH   TYPE NUMBER OF CHOICE ? 2
MIN.        MILLIMOLES ACETIC ACID PRODUCED
      Ø                    1                    2
      I....I....I....I....I....I....I....I....I....I....I
Ø   I* Ø
.1  I       * .28
.2  I              * .57
.3  I                    * .85
.4  I                          * 1.12
.5  I                                * 1.39
.6  I                                     * 1.64
.7  I                                          * 1.86
.8  I                                               * 1.98
.9  I                                               * 2
THE REACTION HAS RUN TO COMPLETION

CONCENTRATION OF INHIBITIOR REMAINING: Ø MILLIMOLES

ANOTHER EXPERIMENT? (1=YES, Ø=NO) ? 1
```

Figure 11

CONVERSION OF ACETYLCHOLINE TO ACETIC ACID (2)

```
AMOUNT OF ACETYLCHOLINE - FROM 0 TO 3 MILLIMOLES ? 2
TYPE OF INHIBITOR - USE CODE FROM 0 TO 5 ? 4
AMOUNT OF INHIBITOR IN MILLIMOLES ? 2
DATA FORMAT: 1=TABLE, 2=GRAPH   TYPE NUMBER OF CHOICE ? 2
MIN.      MILLIMOLES ACETIC ACID PRODUCED
          0                   1                   2
          I....I....I....I....I....I....I....I....I....I....I....I
 0        I* 0
 .1       I * .04
 .2       I  * .09
 .3       I   * .13
 .4       I    * .17
 .5       I     * .21
 .6       I      * .25
 .7       I       * .29
 .8       I        * .33
 .9       I         * .37
 1        I          * .41
 1.1      I           * .44
 1.2      I            * .48
 1.3      I             * .52
 1.4      I              * .55
 1.5      I               * .58
 1.6      I                * .62
 1.7      I                 * .65
 1.8      I                  * .68
 1.9      I                   * .71
 2        I                    * .74
DO YOU WANT TO CONTINUE THE ASSAY? (1=YES, 0=NO) ? 0
CONCENTRATION OF INHIBITOR REMAINING: 2 MILLIMOLES

ANOTHER EXPERIMENT? (1=YES, 0=NO) ? 0
```

By performing experiments of this kind with a computer the student finds out for himself which of 5 possible chemicals actually inhibits the reaction in question and how the concentration of the inhibitor influences the reaction-velocity.

Related to kinetical problems are problems concerned with equilibria. Even in the simpler cases, e.g. in inorganic chemistry, the computer may be a valuable tool in handling such problems, but in biochemistry, where multiple equilibria often exist simultaneously, the computer is particularly indispensable if students in elementary courses are to gain not only knowledge, but also understanding of the complex interaction that takes place in such systems.

The computer is a valuable tool in biochemistry in yet other ways. The first is that biochemicals are often extremely expensive and hence many experiments cannot be performed for economic reasons; they can, however, be simulated on the computer. What is more interesting is that reactions taking place in living organisms are often so complex

that the analysis of the experiments, actual or simulated, cannot be performed without the computer. Biochemical reactions, even in the case of only simpler systems in a test-tube, may easily include as many as ten consecutive and/or simultaneous reactions, often with complicated feedback systems, such as protein synthesis.

The full understanding of such reactions can only be achieved by work with model building and model analysis. In the modern sense of these words such work cannot be performed without the computer. Work with complex model building in biochemistry may moreover help the student to a better understanding of the even more complex laws that govern living organisms and society in its entirety. Such knowledge and understanding will, for generations to come, be not only important but will probably prove to be vital.

Simulation and Modelling in Biology

Many computer programs for use in teaching biology are based on mathematical models. The models themselves can be studied as an aid to the analysis of the topic being considered, or they can be used to simulate an experiment or process which is being studied. When using a simulation it is not necessary for the student to understand the model on which it is based, although it is desirable for him to realise that one is being used. When a model is being studied it is essential for the student to understand it and it may be necessary for him to construct a model or to alter an existing one.

The models that are used can be either deterministic or stochastic. A deterministic model is one in which the variables used do not involve any random element. Given the same initial values, the same results will be obtained no matter how often the model is used. A stochastic model makes use of variables obtained by random process and therefore different results are usually obtained when a model is re-used. Stochastic models are particularly important in modelling and simulating biological phenomena, since they often either involve so many uncontrollable variables that repeatable results are rarely obtained, or have a random element as an essential feature. This is the case wherever gamete formation and fertilisation are present, thus making deterministic models unsuitable. The packages listed in the Appendix that contain stochastic models are EVOLUT, LNKOVR and GENE1.

Most of the packages are simulations. Very few contain models the student is expected to understand, but this is an essential feature of EVOLUT. In this package the student can select from a series of alternatives and use these to model different examples of evolutionary change. The ability to alter an existing model is perhaps the nearest a student can get to designing a model without his being expected to be able to program a computer. It might, however, be possible for him to construct a model if specialised programming knowledge is available.

The need to have a workable mathematical model is a major limitation on the design of simulations. Consequently, those which have been prepared are mainly in the fields of genetics and population studies, since quantitative models are most easily constructed for these topics. Nevertheless, there are features of other types of biological systems which make them particularly appropriate to computer simulation, if the difficulties can be overcome. The systems that maintain more or less constant conditions inside organisms in spite of variation in activity or external environment involve feedback mechanisms which parallel the repetitive process by which computers work. The mechanisms which control breathing, heart beat, blood composition and body temperature are examples of such systems. Ecological studies often deal with large numbers of interacting variables in ways which parallel a computer's manipulation of data stores within it. Food webs, the transfer of energy from one trophic level to another and the interactions of species with their physical environments are possible topics for simulations. In all these cases the models can probably be devised, if adequate data can be found upon which to base them.

In using a simulation it is important that the student and teacher realise its limitations, otherwise two types of error can be encountered. The data the student supplies may be accurate but outside the limits within which the computer model is valid, or the data themselves may be faulty. Thus a simulation of population growth in a particular species can mislead because the model is invalid at high population densities or because faulty information on birth and death rates has been supplied. Errors like these can be reduced by linking the use of the simulation to the student's practical experience. He may be able to make measurements of the variables he has to supply as data to the simulation, such as temperatures or oxygen concentrations in an ecological simulation. Alternatively, he can carry out preliminary experiments that show some of the features of the situation being simulated, such as breeding experiments in genetics before LINKOVR is used. In this way a simulation can extend a student's practical experience, but it should not replace it. When a model is being studied it may be possible to test its validity by seeing the extent to which it fits real data obtained from practical investigations or second-hand sources.

Computers as Calculators

Simulation and models are not the only ways in which computers can be employed in teaching biology. They can be used to perform complex or time-consuming calculations on data the student has collected or with which he is supplied. The most obvious of these applications is in statistical analysis of data, but it is also possible for the

computer to present data in the form of graphs, histograms or maps. A limiting factor in the use of pictorial presentations is that most available computer terminals take a long time to print them out. This time can sometimes be reduced by using batch processing and a line printer, but it is often an advantage to enable a large group to see the output together and to discuss its features while it is being produced. Whether the output is numerical or pictorial, it is important that the capabilities of the computer are fully exploited to produce an annotated output in a form that is easily understood by the student.

Other Uses of Computers

Computers are used to store extensive amounts of data for commercial and research purposes, and it is possible that similar uses may be applicable to biology teaching. The data for storage in a data bank must either be very extensive in order to require a computer rather than a book of tabulated data, or else require access from many different aspects. If the expense in setting up a data bank is to be justified, the data must be reliable and likely to be widely used. This limits the number of possibilities, since there are few sufficiently extensive amounts of data. Nevertheless, the usefulness of data banks containing meteorological information, details of plant and animal distribution and human population census data needs to be explored.

The discipline inculcated by computer use can occasionally be used as an aid to study without access to a computer. Flowcharts are commonly used in preparing and describing computer programs and they provide a convenient form of description for some types of biological process, such as life cycles of plants and animals. Their construction not only helps describe, but also forces the compiler of the flowchart to think carefully and critically about what he is studying. This is true of all the ways in which computers can be used to help in the teaching and learning of biology.

3. THE USE OF THE COMPUTER IN THE TEACHING OF PHYSICS

Experiments in Simulation and Modelling - A French Approach

Physics is probably, of all disciplines, the one in which the use of "informatics" is the easiest to demonstrate. If the main aim of the physicist is the construction of models that explain the outside world and thereby can be used to make predictions, and "informatics" is basically a matter of model-building, then it becomes evident that physicists have always used an approach similar to informatics. However, the concept of "model" in informatics is much broader than the

concept of "mathematical model" which is classically used in physics, and the former includes for instance the "causal model" which cannot be represented by a set of mathematical relations.

From the point of view of "informatics", any approach that aims at an explanation, and hence a prediction (given a set of facts, events and relations between real objects, ending with a symbolic representation of these facts) is a model-building approach. The model which is built is then amenable to a syntactical representation using symbols defined by convention and can hence be simulated on a computer (a set of causal relations can be simulated on a computer despite the fact that it cannot be represented in mathematical notation). The value of the mathematical model is not in question; it has shown its efficiency for centuries, but it is not the only one possible in the teaching of physics.

The teaching of physics, as is true for other disciplines, has long been considered as a transmission of knowledge - this explains the importance given in the textbooks to the laws displayed in heavy print and the formulae which are underlined. It is evident today that given the rate of growth of accumulated knowledge, any teaching system based solely on the transmission of knowledge cannot but fail in the long run. The solution to this dilemma is not to attempt to teach all knowledge but through selected "facts" to teach the specific approach and method of work of the physicist. For this, laboratory work of the "guided discovery" type plays a very important role because of the contact with the real world it implies; there is no question of replacing real laboratory work by simulated laboratory work on a computer.

By using a computer the aim is, through the use of a specific interactive program, to put the student in a pedagogical situation where he is obliged to call upon a certain number of approaches to a problem which are typical in physics (converging series of experiments, choice of pertinent parameters, verification of a guess through experimentation, definition of the validity domain of a model, etc.) and this at a high level of abstraction. During a laboratory session, the student has to co-ordinate many different activities (manual activities, reading of meters, writing down of results, making of calculations, drawing of curves, thinking of what to do next, etc.) the most trivial of which appear sometimes to him as the most difficult. The use of an interactive program on a computer has then to be considered as complementary to the laboratory work, as a pedagogical situation in which the student has to concentrate at a high level of intellectual activity.

Not the least significant advantage of this method is that the student has to reveal his way of thinking about a given situation. His way of building a model becomes controllable and hence can be discussed by the teacher, the goal given to the student being not so

much "to solve a problem" as "to find a method" by which he can solve it. The same difference exists here between "solving a problem" and "finding an algorithm to solve a class of problems" as exists whenever a computer has been introduced. It is in this sense that the teaching of physics is related to "informatics".

The whole of physics should not be taught in this way but a careful choice of topics in different parts of the physics course could bring to the student a greater understanding of what physics really is. One can show for instance that there is not such a thing as one unique model for a given situation, that there are many possible models between which a choice is made for pragmatic reasons (simplicity, efficiency, breadth of the domain of validity, etc.).

Perhaps the following example will explain this more clearly. It was written by a group of physics teachers from secondary schools. In this program, "Laws of Reflection", the movement of an elastic projectile thrown against a wall in a horizontal plane is simulated. The student has normally no prior knowledge of the law of reflection; the aim is to help him discover that law, either in the form of equality of angles of incidence and reflection or in the form of the virtual image.

A point defined by co-ordinates of the plane is given as the target to hit after reflection of the projectile from the wall. The student can choose the point from which the projectile is launched and its point of impact on the wall.

When the student has input these choices to the computer the program gives him information about the success of his shot, saying, for example, by how much to the right or to the left of the target the projectile passed. The student then makes a new experiment based on the result of the first one.

The pedagogical aim is to see :

a) if the student uses the information from the preceding experiment so as to define the next one with a better chance of succes, i.e. whether he makes a converging set of "experiments" or uses a random method;
b) if the student is developing an adequate methodology in the sense that he changes only one of the parameters from one experiment to the next.

If there is no success after 10 trials, the computer prints "Go and see your teacher", because in that case the student's approach is certainly wrong and has to be analysed and corrected.

In the second part of the program, the target is given; the student has to choose the point of impact and to find all the launching points from which this target will be hit, with the same point of impact. This part of the program aims at the discovery of the notion of trajectory.

In the last part of the program four targets and one launching point are given to the student, who has to find the points of impact which will result in hitting the targets. The purpose of this is to suggest the model of the virtual image by the convergence of the trajectories after reflection from the wall and to verify that the student has been able to construct an operational model of the situation after the two first parts.

Experimentation on students with this program has shown that

a) about 5% of the students found the equality of angles without any guidance;
b) about 25% found either the virtual image or equality of angles and the virtual image;
c) about 10% did not succeed in finding any model;
d) about 15% succeeded without being able to formulate verbally the method they used.

There were also some unexpected and very interesting results :

1. the methodological errors made by the students were not random but could be divided into well defined classes;
2. some students found totally unexpected but still correct models to make predictions in the projectile-target situation.

After the one-and-a-half hour experimental session the students and the teacher met to discuss the results obtained. The aim of this discussion was to show :

a) that there are different possible models for a given situation;
b) that these models will all give correct predictions of what will happen;
c) that, from a pragmatic point of view, some models are easier to use than others depending on the specific problem at hand.

Experiments in Simulation and Modelling - An English Approach

In recent discussions about the part that access to a computer can play in science teaching two possible roles for the computer are becoming more clearly defined. On the one hand it is thought that computers can enhance teaching by providing data which are in some respects similar to those that would be produced in a "real experiment". The computer can be used to extend the range of experiments to include those that are too expensive, dangerous, etc., to be done at school. This will be called "simulation".

The other point of view is that the computer can in no sense simulate nature, but it can operate on some model of nature that has been put into it. It is therefore wrong to suggest that what the computer does can be likened to an experiment. It is of course arguable that the great majority of "practicals" done in school science labs are not

really experiments either : they are tasks rigged by the teacher to maximise the chance of the student "getting the right results". But all is not lost, for the act of inventing a simple model and making predictions from it is a characteristic and important part of physics. This will be called "modelling".

To take an example in optics : interference and diffraction phenomena.

In a simulation the program would use some rather complicated formula (which can be found in text books) to calculate the intensity of light at different positions. Students would be asked to choose the slit width, wavelength, number of slits and so on, and the computer would produce values for the intensity in different directions.

In a modelling exercise one could base the program on the model itself rather than the formula it predicts, and allow changes in some of the assumptions that went into producing that formula : do the secondary sources really emit equally in all directions (they don't); is the intensity really uniform across the width of the slit (it isn't)... what difference do these assumptions make, and do they matter ?

Anyone who proposes applying a computer to the teaching of a particular piece of science is familiar with two responses : "Why not do a real experiment ?" or, if it is something which cannot be done in the school laboratory, "Why do you want to do that ?" It might help to clarify the situation to ask some questions about objectives :

a) Why is practical work included in science courses ? Could any of the objectives claimed for practical work be achieved by using computers ?
b) Can any of the general aims of science courses be achieved by using computers ?
c) Does the availability of computers make it possible to strive for other aims not at present recognised but nevertheless desirable ? When the writers of a course list their aims they are naturally influenced by what they think can be achieved with the material they have produced and the techniques currently available : new techniques may make new aims accessible.

A. The purpose of practical work

Kerr (in 1961-3) found that teachers in England and Wales rated ten suggested aims of practical work in the following order for sixth forms.

To encourage accurate observation and careful recording.
To elucidate the theoretical work so as to aid comprehension.
To be an integral part of the process of finding facts by investigation and arriving at principles.

To promote simple, common-sense, scientific methods of thought.
To develop manipulative skills.
To verify facts and principles already taught.
To make biological, chemical and physical phenomena more real through actual experience.
To give training in problem-solving.
To fit the requirements of practical examination regulations.
To arouse and maintain interest in the subject.

Students were given a shorter list and produced a different order when asked to rate the achievements of sixth-form practical work :

Made the phenomena studied more real and interesting.
Made more clear the theoretical part of the course.
Helped me to observe more carefully.
Gave training in manipulative skills.
Taught me to think more scientifically.
Led to the finding out of facts and principles of which I was not previously aware.

Here is an attempt to answer the question posed above : could any of these objectives be achieved using a computer either for simulation or modelling ?

	Simulation	Modelling
Observation	X	X
Elucidation		
Finding-out	✓	✓
Scientific thinking		✓
Manipulative skills	X	X
Verification		
Reality	X	X
Problem solving		
Practical exams	X	X
Interest	✓	✓

This is of course a matter of opinion and is open to discussion. An entry (✓ or X) has only been included where one can be reasonably sure that the computer can or cannot help. Blanks mean "don't know".

Two comments on Kerr's work are relevant :

1. When teachers were asked to rate the same aims in order of importance for earlier years "To arouse and maintain interest in the subject" topped the list.
2. The survey was conducted between 1961 and 1963. Teachers' priorities may or may not have changed since then; and some may even have been influenced by subsequent curriculum projects in science !

B. Aims of science courses

Some of the recent English courses have listed their aims (2, 3, 4, 5). Below is an opinion as to whether any of these aims could be achieved through experiments or through use of a computer to simulate or to model. (It is not at all easy to express general aims concisely and abbreviation may quite possibly lead to misrepresentation). The aims are taken from a variety of science courses and are listed in no special order.

There is some repetition. Again no entry means "don't know".

	Experiment	Simulation	Modelling
Learning in the future			
Understanding physics	✓		
Nature of physical enquiry	✓		✓
Enjoyment	✓	✓	✓
Learning to inquire	✓	x	
Social significance of physics	x		
Recalling information and experience	✓		
Manipulation, following instruction, accurate observing	✓	x	x
Solving a practical problem	✓	x	x
Classifying information			
Interpreting information			
Applying understanding in new situations	✓	✓	
Reporting, discussing			
Place of chemistry in school and world	x		
Accurate observation	✓	x	x
Deducing generalisations			
Inferring results			
Simple experimental design	✓		
Forming hypotheses			✓
Fluency, literacy, numeracy			
Self-discipline and self-programming			
Knowledge of living things	✓		
Making observations and asking questions about them	✓		
Analysing and synthesising data	✓	✓	
Handling information, assessing error and significance	✓	✓	
Judgement of hypothetical statements			✓
Identifying and investigating unfamiliar problems	✓		
Implications of biological knowledge			
Communicating			

C. Aims for simulation and modelling

It is more difficult, but probably at least as important, to ask what new possibilities are created by computer simulation and modelling, as it was to ask whether these techniques can help to achieve any of our currently recognised aims.

The field is new enough for there to be no sources that one can draw on. Some suggestions are discussed below : the order is without significance.

1. Aims for simulation

Since the simulation is a substitute for an experiment one would expect the aims to be similar. But clearly much of what can be achieved in practical work cannot be done through simulation - for example it is difficult to see how simulations could provide opportunity for making and recording observations; for manipulating equipment.

To some extent, depending on the computer program, a simulation could give students the opportunity to design their own experiments. Of course their choice is limited by the program - and it is limited in the laboratory by availability of equipment, time, safety consideration. One characteristic of a simulation is that the student will, in general, learn the consequence of his choice - whether or not it was a sensible one - much more quickly than he would in an experiment. He does not have to wait an hour to see whether a rather slow chemical reaction is proceeding at a noticeable rate at the temperature he has chosen. This may be a disadvantage as it could lead to choices being made with little thought behind them. Most teachers would agree that it is an advantage for students to be able to choose the "wrong" measuring instrument without there being any danger to any of his laboratory equipment.

Simulation may help to illuminate theory in the same way that an experiment of demonstration "to verify..." can. And if the simulation produces results that the student has not been led to expect there is the possibility of "discovery" learning. An obvious advantage of simulation over laboratory experiment is that it is in most cases quicker (once the program is written) and of course can extend the range of observation.

The data produced by the simulation will be much "cleaner" than the readings taken by a student doing a laboratory experiment : there will be no "experimental errors" (unless the program also simulates them). There is a possible advantage here in that the pattern of results may be clearer; the student will be less likely to write off any unexpected result as due to a mistake, for, as students often attribute the results of their experiments to "human error" and therefore treat them as worthless, they are much less likely to disregard a result produced in a simulation as due to "computer error".

Of course a simulation is not the same as an experiment. If, when one does an experiment, one is asking questions of nature, in a simulation one is asking questions of a computer program. Students may be less convinced by a simulation than by an experiment. "Sure the computer gave that result - but only because it was programmed to do so". The fact that the simulation of nature behaves in a particular way does not actually say anything about the way nature behaves. These kinds of considerations may lower the value of simulation for some students. And on a more philosophical level teachers and educators may feel that it is wrong to make any pretence that a simulation can take the place of an experiment. Rather they would present the computer in quite a different role - a device for making predictions based on an assumed theoretical model.

2. Aims of modelling

One of the frequently heard justifications (objectives is hardly appropriate here) for including practical work in a school science course is the rather loosely stated idea "That's what science is; scientists do experiments, students must do experiments so that they can appreciate science as a process by taking part in it". Now doing experiments is only one part of the process of science. Making models which help to understand the world is another.

Students cannot seriously be expected to invent models for themselves; models in the sense of - action at a distance governed by an inverse square law; gas molecules as perfectly elastic hard spheres; light as a wave motion; evolution by natural selection; growth by cell division, and so on. But access to a computer makes it possible to use models to make predictions in a way which may not have been possible before. It might be possible for a student to make choices between alternative models by comparing predictions with observations. He might be able to try modifications to a suggested model which will make its predictions closer to what is observed in nature; to discover the limitations of a particular model; to make judgements about the significance of the discrepancies between the model's predictions and the observations it is supposed to explain.

Where possible and appropriate one would like the student to be able to go back to the laboratory bench to compare the model's predictions with his own observations and to consider the significance and cause of any difference.

There is no doubt that a student who can write his own program can gain most from this kind of activity. It cannot be easy to write a program that is flexible enough to allow the student to modify the model at all freely.

Some of this kind of activity could, and already does, go on without access to a computer. But a computer can both cut out the tedium and greatly extend the range of what can be done.

3. Enjoyment

Although it occurs rather rarely in formal lists of aims most teachers would agree that if they can't make their subject enjoyable they are going to have a harder time teaching it and students are going to learn less.

There is no doubt that for some people using a computer is enjoyable. Part of the enjoyment may come from the feeling of being in control of a very sophisticated and expensive machine which gives a sense of power and achievement. Being successful in a challenging task is a very satisfying thing. A student using a well written program is not exposed to the same possibilities of failure or frustration as he often is in the school laboratory. We should not ignore the possibility of making learning enjoyable.

REFERENCES

1. Kerr, J.F., (1964), Practical Work in School Science, Leicester University Press.
2. Nuffield Advanced Science,Biological Science (1970), Teachers' Guide 1.
3. Nuffield Advanced Science, Physics (1971), Teachers' Handbook.
4. Nuffield Chemistry (1966), Introduction and Guide.
5. Nuffield Secondary Science (1970), Teachers' Guide.

III. MATHEMATICS, SOCIAL SCIENCES, BUSINESS STUDIES AND THE HUMANITIES

1. MATHEMATICS - REPORT OF THE STUDY GROUP

General

In mathematics the computer has a broad role to play. Current practice in several countries is to use the computer as an aid in studying the usual topics in the mathematics curriculum. Students of mathematics should write programs to :

a) perform tedious, repetitious calculations;
b) demonstrate or reinforce concepts; and
c) solve problems.

The last is fundamental. In preparing a problem for computer solution the student has to analyse the problem and then to devise an algorithm. Computing methods can influence mathematics teaching even where computing itself is not used. For instance, the construction of flow charts now earns a place in many courses. The value in mathematics of simulation and modelling is already obvious to those who have used it even a little. Packages have been used to produce graphs and solve problems in probability and statistics but there is the need for further development. In the case of graphs, pupils are able to study a whole family of curves in less time than it takes to draw one special case. In the study of probability, a great number of trials can be conducted. In statistics, since the numerical processing is done by computer, real data can be used instead of artificial textbook examples. This in fact makes statistics meaningful - a task hitherto difficult.

For pupils of all ages many topics can be enriched by the use of a computer package which may be used in several different ways according to the level of the pupil. For example, it may be used to illustrate a topic by a student who has as yet no grasp of the mathematical principles underlying the problem but who is interested in the problem itself. The same package may be used in a more sophisticated way by students who do appreciate the underlying mathematics and who may be capable of handling it themselves and even be able to develop a similar program.

Numerical and Statistical Applications

The introduction of a mathematical idea by a numerical approach has been used in mathematics courses in the past, but usually stopped after a few simple examples have been worked out because the calculations were too cumbersome and took too long.

The computer makes it possible to provide a fuller numerical basis on which to develop a concept. It is no longer necessary to be restricted to simple problems nor to cases where calculations are to be performed on simple figures. It is possible to introduce a topic through a variety of problems thus motivating the student and leaving the full understanding of the mathematical content to a later stage. A student can acquire a better grasp of a mathematical relationship when he can examine sufficient examples to recognise the emerging pattern.

Much time in courses has always been spent on techniques that are relevant to certain special cases only (e.g. special types of equation, integrals of special functions) whereas a carefully chosen numerical method may be applied to a whole range of cases, including those that were not even possible to handle analytically. In some cases, even where the analytical method is well known, a numerical approximation may be much quicker and just as acceptable.

A numerical introduction to analysis for pupils in the final years of secondary school seems to be a natural continuation of the foregoing ideas. The choice of a numerical method for the solution of a particular problem needs much care and this can only have a positive influence on the awareness of pupils in the use of mathematics.

There is likely to be a shift of emphasis in school courses, with more time being given to numerical methods, less to the special analytical techniques that are so prominent at present. This could well mean that more students will be able to go further in their mathematical studies.

2. REPORT OF THE SOCIAL SCIENCE AND BUSINESS STUDIES GROUP

The subjects in Social Science to be considered here are Economics, Geography and Demography.

Simulation and Modelling

Simulation and modelling is of much assistance in the study of many of the subject areas in social sciences and business studies. The use of a computer model allows one to do away with much of the tedium involved in the use of manual models. Further, it allows one to use more sophisticated models involving more complex relationships and thus provides a better-quality simulation.

With regard to the student's understanding of a model that may have a fairly high degree of sophistication, it is necessary to introduce the student initially to a much simpler version of the model. This could involve using manual methods in the first instance, building up to a more complex model which finally enables the student to experiment with the computer model. Simulation should be used to develop the understanding of the relationships that exist between the factors of the system being considered. However, the straight substitution of values into a model on a trial-and-error basis is a little value.

Business Studies appears to be an extremely promising area for model development. The computer can simulate problems which deal with the optimum time to replace equipment that gradually becomes less effective, due either to wear and tear resulting in probability of failure increasing beyond tolerable limits. Production scheduling is another example in which models could be made to simulate the situation that exists between production and demand. Critical Path Analysis is an interesting application since it is easy to understand and many realistic examples of its use can be built into computer models. Other areas where development could take place in business studies are stock control, production control, accounting, transportation problems. Management games involving students in role-playing and in the making of competitive decisions are most useful and there is the need for the development of more games of this type.

In geography some models such as farm games already exist. Further development of any such models that are found to be over-simple could provide for greater flexibility and sophistication so as to meet the educational needs at different levels of student ability. Other areas where development can usefully take place include the simulation of weather patterns and urban planning.

In demography which concerns itself with population dynamics, the computer package "USPOP" dealing with human population growth is of value. It would be of further value to develop a model of the dynamics of working populations as affected by various influences of economic factors.

Information Retrieval and Data Banks

In social sciences and business studies it is beneficial to allow students to have easy access to a wide range of data collected from many sources, local and world-wide. Although a general data bank to which any subject could have access would be most useful, smaller subject-based data banks are more practicable and can play a useful role. In considering the setting up of a data bank and the fact that real data would be used, it is suggested that this data could be bought or acquired in certain cases from sources such as banks, insurance companies or meteorological offices. By doing so, much of the cost

incurred in both time and labour of continually updating the data base would be avoided.

With regard to information retrieval from files derived from data bases, there is a distinct need for a program which allows the easy creation of files. This would be capable of automatically setting up a file with characteristics chosen by the user. The value of such a package in business studies would be in allowing files with different structures to be studied. Differently structured files would provide the basis for studying different file-accessing techniques. The same package could be used to set up the data file necessary for a mini stock control system working with data acquired from within the school itself and thus it becomes more meaningful and personal to the students.

Numerical and Statistical Application

In social sciences the use of the computer allows one to deal with statistics concerning larger samples than one could otherwise cope with manually.

From the field of demography calculation using census data, accumulated over several census periods, could be performed to provide statistical information in population rate of birth, death and fertility as well as population migration trends over different time intervals. In addition to statistical analysis the computer is also able to provide pictorial representations of this data in the form of histograms or maps. In a similar manner data applicable to geography can be handled with equal facility.

Applied to business studies, future trends such as sales can be predicted on statistical data of previous sales and given probability factors. Calculations on mortgage rates and actuarial formulae can be included as examples of numerical applications within business studies.

Present Situation

Some of the existing packages are found to be very interesting and to have great potential but others are of a trivial nature, or not at secondary level or technically oriented towards the computer.

There is a danger that, if a pupil is presented with a computer model without a careful introduction to the subject, he will adopt a "trial and error" approach. It is often necessary, therefore, for the teacher to introduce the concept used in the model before allowing the student to investigate the computer version. Again, it may be necessary to restrict the complexity of the computer model initially, and after some experience the restrictions can be progressively removed.

Some packages have been written in a speculative way by computer specialists, due to the lack of understanding of the subject teacher

of the possible applications of computers to his subject. Computer specialists have shown themselves ready to try to bridge the gap but this is not enough. As long as packages are produced either solely or mainly by computer specialists they will not be as relevant as they should, nor will they be easily accepted by the subject specialists. The subject teacher should provide the idea for the package which should be embedded in a particular course with the stress being on teacher's notes and pupil's material and not on the computer program.

3. REPORT OF THE HISTORY, LANGUAGES AND LITERATURE GROUP

The lack of substantial research in and development of the use of the computer at the secondary stage in these subjects is perhaps an indication of the difficulty in identifying functions for it.

Though in higher education some games and simulations have been developed in history, little has been done at the secondary stage. However, it seems possible that for senior students simulation or games that illustrate the causality - or the lack of it - that lies behind a historical event could be of value. It is recommended that national, or international, groups of experts should meet to consider the desirability of this approach and if in favour of it, research should be initiated. At the moment little is known about the costs of establishing and maintaining data retrieval systems. Research into this is certainly desirable, and a possible field would be modern history perhaps with emphasis on economic or social content where ready access to information would be valuable.

In languages, drill and practice using a computer does not appear to be intrinsically better than by other methods and is not cheaper; it also fits badly with modern concepts of teaching living languages. However, in the "dead" languages which are increasingly taught to small groups, sometimes by short intensive courses with considerable individual study, a possible usage can be identified in either the direct teaching of grammatical complexities or perhaps diagnostic testing of grammatical competence with remedial teaching using CAI. This may therefore be an area for initiating research but, before this is done, experts in the teaching of the "dead" languages should consider whether or not it is desirable. Research into the teaching of grammatical structure using a computer as a tool should be continued; this is particularly useful since the object of this is to improve the teaching/learning process.

In literature at school level no way to use the computer that satisfies the main criteria can be identified at present.

IV. MATERIALS AND TEACHER TRAINING

This chapter is concerned with topics that are common to the various subject areas covered by the report.

1. DESIGN OF MATERIALS

As can be seen from the examples given in Chapter II, emphasis has been placed on enrichment and enhancement of students' learning experiences rather than on instructional methods. The materials should be structured so as to be integrated, alongside other resources normally used by students, into a particular course. It is necessary to say that this material is not easy to design and that the problems are not ones of computing by and large, but of pedagogy. The computer must be providing an experience not possible in other ways and such materials must be based on the requirements of teachers of the subject.

One most important criterion in the design of simulation material is that the student should be thinking in the real world. It is essential that he should be involved in the same decision making experiences as he would be if performing a real experiment. Can we create for him the atmosphere of working at a laboratory bench or in a natural environment where he has to consider the control, variation and observation of the parameters of the system ? The student's existing knowledge of science should help him to discover more as the results of his experiment are analysed by him. We must promote the practice of scientific method and it may be that this can be done quite effectively through the slightly more structured simulation experiments. This is certainly an important aim though it is not easy to be sure that it is always achieved.

How can the simulation material be designed so that this aim is achieved ? An approach has been to consider the computer based experiment as only a part of the total teaching package. Other elements could include :

a) a related introductory real experiment;
b) a topic booklet (or teaching material) leading to the simulated investigation;
c) a single or a series of simulated investigations;

d) assignments requiring the careful analysis of the observations and results of the simulated experiment and perhaps creating the need for the student's own design of a new investigation;
e) a further real experiment (perhaps rarely possible) or literature investigation.

It is the blend of these elements into the total package that is critical to the acceptance and value of this approach to teaching aspects of science.

2. GUIDELINES FOR PACKAGE DOCUMENTATION

Too many "packages" that are currently available consist of a computer program and little else. As it is felt that this is inadequate if teachers are to make effective use of the materials, the following minimum guidelines on package documentation are suggested.

The computer package should contain at least

1) Teacher's Notes,
2) Student's Notes and
3) Program Documentation,

all of which should be designed to meet the needs of a particular course.

1. Teacher's Notes

The teacher's notes should contain the following :

i) Aims of the material;
ii) Details of any assumptions made in the design of the material;
iii) Suggestions for teaching methods indicating links with existing courses and materials, e.g. laboratory experimentation;
iv) Comments on problems contained in the pupil's notes;
v) A sample computer print-out of the execution of the program.

2. Student's Notes

The student's notes should contain the following :

i) A general résumé of the subject matter to be dealt with;
ii) The specific objectives of the package;
iii) Specific problems to start, with more open-ended problems to follow;
iv) In cases where students are intended to understand the model, all underlying assumptions must be given;
v) In some cases it may be appropriate to include a computer print-out.

3. Program Documentation

The computing element of a package should consist of :

i) Either a program tape, cards or a listing of the program;
ii) Program operating instructions if not self-documented;
iii) A flowchart and a list of variables together with their functions within the model.

Notes :

a) It may be desirable in certain cases to have additional papers as resource material for student and/or teacher.
b) The items listed in (3) above may form part of the teacher's notes.

Packages once written must be tested to determine whether the design objectives of the package have been achieved or not. It is quite possible that a package could have pedagogical applications that have not occurred to the authors. It is therefore necessary to make provision for "critical feedback" when developing a new package.

3. DISSEMINATION OF MATERIALS AND INFORMATION

Since the cost of package design, writing and testing is extremely high, priority should be given to resolving the problem of dissemination of package material and information both nationally and internationally so as to keep costs to a minimum and to achieve maximum impact. To do this, information should be disseminated in as many different ways as possible, viz :

1. Through normal channels used to disseminate information of interest to subject teachers such as associations, conferences, newsletters and bulletins.
   It is important that teachers should encounter this information on computer-based materials in the normal course of events through the same media as are used to disseminate the more traditional subject-based material. Other possible channels might be :
2. Local education newsletters;
3. General computer education literature;
4. School inspectors or advisers;
5. The CERI International Information Centre for Computing in Secondary Education at Moray House in Edinburgh and its newsletter;
6. Subject-based centres established through the Council of Europe such as the Geography Centre at Strasbourg;

7. European Documentation and Information Service for Education, an educational computer-based data bank;
8. Television and radio. For example, in Sweden time is already given to an educational information service on television.

The responsibility for forming the links necessary for dissemination belongs particularly to all full-time workers in curriculum development. To facilitate dissemination between countries, the International Information Centre and its associated national correspondents will play an important part. In order that the International Centre should operate effectively and efficiently, national centres (or a number of centres within a country, if necessary) are essential. The national centre (or centres) will have the responsibility of disseminating information received from the International Centre to teachers in that country, as well as the responsibility of transferring information arising from within that country to the International Centre. To help with the dissemination of information on packages a "framework" document, similar to those contained in the appendix, will be used in response to enquiries on package material. This and other information will also be disseminated through the regular publication of the international newsletter entitled "The International World of Computer Education".

It is important that advice on the use of computer-based materials should be presented to those concerned with administrative decisions on the implementation of curriculum development. The timing of this advice is, in many cases, critical.

4. EDUCATION OF TEACHERS

The situation at present is that too few teachers are capable of using and developing computer package material. In particular, the use of the computer as a supplement to other resources commonly used in the teaching of a subject is not widely known. In view of these facts, the most urgent need is for courses to be provided for those who are already teaching and those studying to become teachers.

Such courses are envisaged at two distinct levels :

a) a basic course to make use of existing packages appropriate to their own disciplines, and
b) a higher level course for those who, it is hoped, will become involved in the development and writing of computer packages.

Against the background outlined above, and while recognising the teacher shortage in certain countries, it is essential that teachers be exposed to the potential of the computer in their own subjects. To achieve this the following guidelines are included :

1. Teachers should be offered the opportunity of voluntary secondment to an appropriate centre on a full-time basis for a course ranging from 1 month to 1 year, depending on the subject and the level of the course, in order to gain experience in computing and to investigate the relevance of computing in their own subject.
   It may be of value to split a course into two or more parts so that teachers can test, in the classroom, the ideas they have developed before returning to complete the course.
2. Each selected school should send a group of teachers rather than a single teacher on such courses. This is necessary to maintain continuity in cases where teachers are promoted or transferred to other schools.
3. On return from secondment teachers should be supported by whatever local computing facilities are available, but preferably by a local education computing centre (with programming assistance and typing and printing facilities) which will provide a focus for working groups both on a subject and on an interdisciplinary basis.
4. For those being trained for teaching there should be available optional courses which would allow them to see the potential of the computer.

There is also the need for teachers with an in-depth knowledge of computer science as well as their own subject. To this end it is suggested :

5. That during their diploma or degree course students should be encouraged to study computer science in depth.

Although it is recognised that the costs involved in undertaking any such programme concerned with the education of teachers would involve a substantial investment, it is nevertheless vital if the use of the computer as a resource in education is to be successful.

Appendix

EXAMPLES OF COMPUTER-BASED TEACHING MATERIALS CURRENTLY AVAILABLE

The following brief descriptions of computer-based teaching materials are intended to provide an indication of the range of topics covered. This is only a small sample of the material currently available, and many more centres than those named on the following pages are involved in the production of program packages.

TITLE - LOCKEY

Source : Huntington II Computer Project.

Materials : Student Manual, Teacher Manual, Resource Manual, Program.

Date of this outline : October 1971.

Subject and Specific Topic :
Biology. Biochemistry - Lock and Key Model of Enzyme Action

Educational Aims :
To provide a learning experience in which the student comes to associate substrate shape with enzyme specificity.
To allow investigation of competitive inhibition of enzymes, with a variety of substrates.

Advantages of the use of this material :
Analysis of enzyme kinetic involves mathematics usually beyond the ability of secondary school students. Traditional approaches are either high qualitative or very lengthy. Computer simulation frees the student to explore a wide range of experimental approaches and design appropriate controls.

Prerequisites on the part of the student :
Students should be familiar with
a) Structure and function of enzymes
b) Substrate specificity of most enzymes
c) Concept of the term millimole
d) Concept of a control for an experiment.

Student involvement :
Students design their own biochemical experiment involving the enzyme acetycholinesterase and possible enzyme inhibitors. Selection of substrate level, inhibitor type (if any) and amount of inhibitor allows the computer to produce data simulating an actual test in either graphical or tabular format.

Time of involvement for an individual or small working group of students :
Three to four hours including one hour of computer access.

Computing facilities :
Computer terminal connected to computer having interactive BASIC using the TAB function for graphing. 8,000 words storage required.

Stage of development :
Material available commercially in final form.

Further information :
All materials, including punched paper tape of program available from : DEC Educational Publications, Program Library, Digital Equipment Corporation, Maynard, Massachusetts 01754, U.S.A.

Development of LOCKEY was partially supported by the National Science Foundation, Grant GW-5883.

TITLE - PH

Source : Huntington II Computer Project.

Materials : Student Manual, Teacher Manual, Resource Manual, Program.

Date of this outline : September 1973.

Subject and Specific Topic :
Biology. Biochemistry - pH specificity of enzymes

Educational Aims :
To provide an investigation which links structural knowledge of an enzyme to its chemical behaviour.

Advantages of the use of this material :
The techniques for determining precise enzyme activities at various pH values is usually too difficult to be performed in a biology survey course, yet this material is a part of most biology programs.

Prerequisites on the part of the student :
a) Knowledge of the catalytic behaviour of enzymes
b) Basic structural knowledge of the chemical make-up of enzymes
c) pH scale for hydrogen ion concentration
d) Primarily designed for students aged 14-20.

Student involvement :
Students select from one to four acidic or basic amino acids to be found at the active site of an enzyme. They can specify what charge state is required for enzyme activity and over what pH range they wish to investigate this particular enzyme. The computer will generate a graph of relative enzyme activity over the specified pH interval.
Student materials contain both specific and general exercises.

Time of involvement for an individual or small working group of students :
Varies according to the number of investigations carried out. Two hours minimum including 15 minutes at a computer terminal are required.

Computing facilities :
Computer terminal connected to a facility using an interactive BASIC, the TAB feature is required for output of the graph. Minimum 8,000 words storage required.

Stage of development :
Commercially available in final form.

Further information :
All materials and punched paper tape of program available from : DEC Educational Publications, Program Library, Digital Equipment Corporation, Maynard, Massachusetts 01754, U.S.A.

The development of pH was partially supported by the National Science Foundation, Grant GW-5883.

TITLE - NUTRIT

Source : P. Aboudarham, M.F. de Beaulieu, Danielle Copin-Montegut, D. Diaz (FRANCE)

Date of this outline : June 1973.

Subject and Specific Topic :
Biology. Study of calorie requirements of human beings.

Objectives in terms of learning and/or attitude changes in the student :
To increase the understanding of students concerning the calculation of the calorific needs of each individual, and to give them the opportunity to discover necessary and sufficient diets.

Advantages of the use of this material :
Advantages of this approach are related to the methodology. The student is able to produce a number of examples and to manipulate for each the parameters which he chooses.

Prerequisites on the part of the student :
The student must know the simple organic requirements : glucose, protein, fats and their function.
The maximum age of students to undertake this work is about 14-15.

Student involvement :
There are two parts in the program :
1. The calculation of the calorific allowances the student chooses for a subject have been given, the height, the weight, the age, the sex, the temperature, etc., and also indicate the degree of activity in 24 hours - the hours of rest, of light work, of exertion, of sleep, etc. He is able to vary one of the parameters, change the activity of the subject or consider a number of people successfully.
2. The establishment of a menu dependent on previous calculations, and the student is able to test various menus and so be able to appreciate the nutritional requirements.

Time of involvement for individuals or group of students :
The student will need to read the paper and spend about 1 hour on these and a further hour using the terminal. The total time will depend upon the number of questions which he tries to answer.

Computing facilities :
Computer terminal supporting interactive BASIC.

Context of use for which the material has been designed :
This program is used in a general study of human nutrition and is appropriate for any course which considers this study.

TITLE - POLUT

Source : Huntington II Computer Project

Latest Revision : August 1971.

Materials : Student Manual, Resources Manual, Teacher's Manual, Program.

Subject and Specific Topic :
Biology. Ecology - water pollution.

Educational Aims :
To learn the effects of water body type, waste dumping rate, water temperature, sewage treatment, and waste content on oxygen level and organic waste levels.

Advantages of the use of this material :
Evaluation of oxygen content and total organic content calls for complex chemical procedures. Use of the POLUT simulation allows the student to study these factors in a wide variety of environments, simply and quickly.

Prerequisites on the part of the student :
a) meaning of parts per million (ppm)
b) primary and secondary waste treatment procedures
c) temperature effects on water
d) designed for students of 12 to 18.

Student involvement :
Student selects the type of body of water, water temperature, rate of waste dumping, type of waste treatment (if any). The computer will then apply a model that calculates oxygen content and biological oxygen demand over a period of thirty days. Data is output as either graph or a table or both.

Time of involvement :
1 to 2 hours including one half-hour access to a computer terminal.

Computer facilities :
Computer terminal connected to a computer using BASIC language having the TAB function. 8,000 words of storage are required.

Stage of development :
Final version commercially available.

Further information :
All materials including punched paper tapes of program available from : DEC Educational Publications, Program Library, Digital Equipment Corporation, Maynard, Massachusetts 01754, U.S.A.

POLUT was partially funded through the National Science Foundation, Grant GW-5883.

TITLE - CO-EXIST

Source : Chelsea Science Simulation Project.

Materials : Teacher's Notes, Student's Notes and BASIC program.

Date of this outline : March 1974.

Subject and Specific Topic :
Biology. Population dynamics - competition between two species of animals.

Educational Aims :
To help the student (i) learn how population may alter with time when two species share resources in the same environment, (ii) appreciate how the analysis of the component parts of a problem can develop an understanding of the whole problem.

Advantage of the use of this material :
It is difficult to carry out experiments in population dynamics because of the numerous factors which affect the outcome and the time required to perform the breeding experiments. However, experiments of this type are necessary to help the student to accept or reject the Gausean competitive exclusion principle. This simulation allows a student to investigate the behaviour of a simplified model of the population dynamics of one or two hypothetical species.

Prerequisites on the part of the student :
a) An elementary understanding of the demands made by species on their environment and a non-mathematical understanding of the sigmoid growth curve.
b) Academic students aged 16 - 18 years.

Student involvement :
The student systematically chooses values for the number of offspring, generation times, initial populations and inhibitory factors, and is presented with a graph of the population changes and the equilibrium populations.

Time of involvement for an individual or small working group of students :
For preparation, use, analysis and discussion a total time of 3 - 4 hours would seem appropriate; 1/2 - 1 hour of this being with access to the computing facility.

Computing facilities :
Computer terminal connected to a computer providing interactive BASIC. 2100 words (of 16 bits) working storage are needed.

Stage of development :
Trial material in use in a number of secondary schools. In the light of feedback from the first two drafts the text has been revised. Final text ready for publication.

Further information :
Computer Unit, Chelsea Centre for Science Education, (University of London), Bridges Place, London SW6 4HR.

TITLE - EVOLUT

Source : Chelsea Science Simulation Project.

Materials : Student's Notes (Draft 2) Teacher's Notes (Draft 2) and BASIC program (Version 4).

Date of this outline : December 1973.

Subject and Specific Topic :
Biology. Natural Selection and Evolution.

Educational Aims :
The student should appreciate that differential survival occurs, some forms surviving in preference to others. If variation is inherited then this factor produces micro-evolution. This can be studied as an on-going process.

Advantages of the use of this material :
The process of counting coloured peas is tedious; by using the computer it becomes faster and is not prone to error. The pupils' appreciation of the action of Natural Selection by realisation that changes showing a relatively differential survival is sufficient over a number of generations to alter the majority of a population.

Prerequisites on the part of the student :
An elementary knowledge of Genetics and in particular the meaning of :

a) Alleles, dominance and recessiveness, homozygotes and heterozygotes.
b) Ecological habitats.
c) Percentages.

Student involvement :
Be given the text for preliminary reading. A general class discussion on the evidence leading to the need to test the hypothesis that inherited variations showing a small positive survival value are sufficient to produce micro-evolution within the population.
Test the hypothesis
a) by pea model - discuss deficiencies of test mechanisms,
b) by computer - discuss results.
Follow up with extension of discussion to broader evolutionary issues.

Time of involvement for an individual or small working group of students :
For preparation, use, analysis and discussion a total time of 3-4 hours would seem appropriate, 1/2 to 1 hour of this being with access to the computing facility.

Computing facilities :
Computer terminal connected to a computer providing interactive BASIC. 2200 words (16 bits) of working store are needed.

Stage of development :
Second draft material has been produced but has been used by few students in English secondary schools.

Further information :
Computer Unit, Chelsea Centre for Science Education, (University of London), Bridges Place, London SW6 4HR.

TITLE - LINKOVER

Source : Chelsea Science Simulation Project.

Materials : Teacher's Notes, Student's Notes and BASIC program.

Date of this outline : March 1974.

Subject and Specific Topic :
Biology. Genetics - construction of linkage maps.

Educational Aims :
To give the student practical experience in the technique of constructing linkage maps and thus develop his understanding of the importance of linkage and crossing-over during meiosis.

Advantage of the use of this material :
In order to construct linkage maps large numbers of precise breeding experiments must be carried out. This involves too much time and too many organisms for it to be practicable in schools. This simulation allows a map of a group of 10 linked genes in hypothetical organism to be constructed without the labour of breeding organisms.

Prerequisites on the part of the student :

a) A knowledge of elementary genetics, including the fact that linkage between genes is a consequence of their being on the same chromosome.
b) Mainly for academic students aged 16 - 18 years.

Student involvement :
The student has to select the genes for trihybrid crosses and is presented with the offspring produced when a testcross is carried out. From this data the student has to determine the order of the genes on the chromosome and the degree of linkage between them.

Time of involvement for an individual or small working group of students :
3 - 4 hours for preparation, use, analysis and discussion. This includes 1/2 - 1 hour with access to the computing facility.

Computing facilities :
Computer terminal connected to a computer providing interactive BASIC with simple string facility. 3500 words (of 16 bits) working storage are needed.

Stage of development :
This material has been tested in a few British secondary schools, in connection with the Nuffield Advanced Biological Science curriculum. Final texts prepared and ready for publication.

Further information :
Computer Unit, Chelsea Centre for Science Education, (University of London), Bridges Place, London SW6 4HR.

TITLE - USPOP

Source : Huntington II Computer Project.

Materials : Student Manual, Teacher Manual, Resource Manual, Program.

Date of this outline : June 1973.

Subject and Specific Topic :
Biology. Population Study - Human Population Growth.

Educational Aims :
To allow exploration of the effects fertility, sex distribution, age distribution, age specific birth distribution and sex of offspring have on population growth in a human population.
To develop a realistic feeling for factors necessary to slow population growth.

Advantages of the use of this material :
No simple model provides a totally satisfactory model for human populations as the structure of the current population strongly modifies the growth of the population in the future, for a period of approximately 70 years. The complex computer model allows the student to carry out many interesting investigations without complex mathematical manipulation.

Prerequisites on the part of the student :
a) Meaning of fertility in a human population
b) Current conditions within the populations under study.

Student involvement :
The student plays the role of a demographer carrying out a population projection based on a set of student-designed assumptions. Various types of output may be selected by the user.

Time of involvement for an individual or small working group of students :
Variable, minimum investigation 2 hours including 15 minutes' access to computer terminal.

Computing facilities :
Computer terminal connected to a computer using interactive BASIC having a TAB function for graphical output. Minimum of 8,000 word storage required.

Stage of development :
Materials available commercially in final form.

Further information :
All materials, including punched paper tape of program available from : DEC Education Publications, Program Library, Digital Equipment Corporation, Maynard, Massachusetts 01754, U.S.A.

USPOP was partially funded through the National Science Foundation, Grant GW-5883.

TITLE - MENDEL

(The material is in French)

Source : FRANCE - Mrs. P. Aboudahram, Mrs. D. Copin, Mrs. M.F. de Beaulieu, Mr. R. Diaz and Mr. C. Lafond.

Date of last revision : November 1973.

Subject and Specific Topic :
Biology. Genetics - Mendel's Law.

Educational Aims :
- Rediscovering the laws of hereditary transmission of character
- Training in strictly logical reasoning
- Introducing the pupil to the methods of biological science
- Use of the computer in biological science.

Advantages of the use of this material :
- Each pupil works at his own rate
- Initiative left to the pupil
- The results of the experiments are sufficient to give the pupil a basis for his reasoning
- The listing can be used to assess the pupil's successes and errors, his quickness or slowness and his tenacity.

Prerequisites on the part of the student :
General knowledge of the reproduction of living organisms (pupils in the first and terminal classes, i.e. from 16 - 18).

Student involvement :
Using the results of the monohybridism and dihybridism experiments, the pupil has to discover the laws of hereditary transmission of character, being guided in his reasoning by the comments, suggestions and questions in the manual.

Time of involvement for individuals or group of students :
A two-hour session for monohybridism
A two-hour session for dihybridism.

Features of the computer system :
Language : BASIC or L.S.E. Time-sharing system.

Stage of development :
Program and student's manual are available.
Qualifying tests have begun.

Further information :
Mr. Lafond, Section Informatique et Enseignement, Groupe Informatique et Sciences Naturelles, 29, rue d'Ulm, 75230 Paris Cedex 05, France.

TITLE - RKINET

Source : Chelsea Science Simulation Project.

Materials : Student's Notes, Teacher's Notes and BASIC program.

Date of this outline : December 1973.

Subject and Specific Topic :
Chemistry. Reaction kinetics - investigation of factors affecting rates of reactions.

Education Aims :
To help the student learn about
i) the effects of changing factors, e.g. temperature which affects the rate of chemical change and
ii) the use of mathematical models in computer simulation of chemical processes.

Advantage of the use of this material :
Although the student can gain practical experience on reaction kinetics there are many systems which are impossible to study in school because the necessary time and equipment are not available. This simulation enables the student to obtain wider experience and understanding of reaction kinetics than he would be able to otherwise.

Prerequisites on the part of the student :
a) A knowledge of chemical kinetics appropriate to a British sixth-form chemistry course.
b) Academic students aged 16-18.

Student involvement :
The student first carries out a simple exercise in mathematical modelling, comparing computer-derived results with his own experimental ones. He then uses models stored in the computer to simulate other experiments choosing suitable values of parameters which represent experimental conditions. This gives him valuable experience in designing such "experiments" and a practical knowledge of characteristics of chemical systems which he might not obtain in any other way.

Time of involvement for an individual or small working group of students :
For preparation, use, analysis and discussion a total time of 3-4 hours would seem appropriate, 1/2 - 1 hour of this being with access to the computing facility.

Computing facilities :
Computer terminal connected to a computer providing interactive BASIC. 2500 words (16 bits) of working store are needed.

Stage of development :
Three drafts have been used by students in English secondary schools and colleges. Final draft now going for publication.

Further information :
Computer Unit, Chelsea Centre for Science Education, (University of London), Bridges Place, London SW6 4HR.

TITLE - REFØ, REF1, REF2,

Source : Group : "Computer Science and Physical Sciences"
Ecole Supérieure d'Electricité, Paris.

Materials : 3 program tapes, document for teachers and document for pupils.

Date of this outline : November 1973.

Subject and Specific Topic :
Physics. The phenomenon of reflection (simulation).

Educational Aims :
Behavioural - to have a systematic and coherent method of investigation. To perform a series of convergent experiments. Cognitive - model can be used to explain the phenomenon of reflection.

Advantage of the use of this material :
The program simulates the reflection of projectiles at a plane surface. This simulation makes it possible (i) to study reflection in a form different from the traditional one (optical), and (ii) to separate manipulative difficulties from difficulties in the theory (by placing the pupil at a higher level of abstraction).
It makes it possible to follow the thought processes of the pupils, to bring out those which are mistaken and correct them.
It gives more freedom to the pupil's creativity.

Prerequisites on the part of the student :
Know how to plot a point on a plane by its co-ordinates.
"Second cycle" pupils. Age 15 - 18.

Student involvement :
After reading the documents the pupil will :
1. hit a target C by reflection (the pupil chooses the co-ordinates of the launcher S, and the point of reflection I).
2. hit 4 fixed targets from one fixed point S.
The pupil interprets his attempts by reporting the results obtained on a graph.

Time of involvement for an individual or small working group of students :
For the introduction, using the program, analysis and discussion, a time of 2 hours seems necessary with access to alphanumeric terminal for 1 - 1 1/2 hours.

Computing facilities :
Memory space occupied : about 3,000 words, language used LSE.
Video consoles connected to a computer with an LSE compiler.

Stage of development :
This program has been used with about 30 pupils.

Further information :
Group "Informatique et Sciences Physiques" Mr. Hebenstreit, 12, Avenue Pierre Larousse, 92240 - MALAKOFF.

TITLE - INTERP

Source : Chelsea Science Simulation Project.

Materials : Student's Notes, Teacher's Notes and BASIC program.

Date of this outline : November 1973.

Subject and Specific Topic :
Physics. Single and multiple slit diffraction and interference.

Educational Aims :
To let students investigate how the interference patterns are affected by slit width, slit spacing, number of slits and wave length; how sharpness and intensity of the maxima increase with number of slits; and how the interference pattern produced by multiple slits is affected by the diffraction pattern due to the width of each slit.

Advantage of the use of this material :
The investigation mentioned above cannot at all easily be performed by a student in a laboratory. It is not intended that this material should replace usual observations with single-slit, double-slit and diffraction grating; but it can help to bridge the gap between observations of 2-slit pattern and spectra produced by grating.

Prerequisites on the part of the student :
Observation of some interference effects and simple explanation in terms of wave model of light.

Student involvement :
A series of questions directs the student to varying the parameters of the "experiment" in a way that leads him to useful observations. Output is obtained as graphs of intensity vs. angle of diffraction.

Time of involvement for an individual or small working group of students :
Total about 1 1/2 hours, not necessarily in one session, perhaps half of this at the terminal.

Computing facilities :
Computer terminal connected to a computer providing interactive BASIC. 1600 words (of 16 bits) of storage are needed.

Stage of development :
Second draft material tried with secondary school children in England; several improvements suggested including possibly replacing the whole module with one which concentrates on the underlying model and its assumptions.

Further information :
Computer Unit, Chelsea Centre for Science Education, (University of London), Bridges Place, London SW6 4HR.

TITLE - MECAØ, MECA1, MECA2

Source : Group : "Computer Science and Physical Sciences",
Ecole Supérieure d'Electricité, Paris.

Materials : 3 program tapes; document for teachers and document for pupils.

Date of this outline : June 1973.

Subject and Specific Topic :
Physics. Study of the movement of a body sliding down an inclined plane, starting from rest (simulation).

Educational Aims :
Behavioural - to carry out a systematic and coherent investigation of the variables which influence a physical phenomenon and the relationships between these variables.
Cognitive - the parameters which control such movement and their effect - the condition for there to be movement - a mathematical model for sliding without friction on an inclined plane - a mathematical model for sliding with solid friction on an inclined plane.

Advantages of the use of this material :
It makes possible :
- experiments which could not be performed (for example, variation of g)
- a very large number of experiments
- by placing the student at a high level of abstraction, to separate the experimental difficulties from difficulties in theory.

Prerequisites on the part of the student :
Kinematics of straight line motion; definition of angle and of coefficient of friction.
"Second cycle" pupils, now aged 16 - 19.

Student involvement :
After reading a document, the student must study, in simulation, the movement of a body sliding down an inclined plane, choosing the experimental conditions himself.

Time of involvement for an individual or small working group of students :
For the introduction, using the program, analysis and discussion a time of 2 hours, with access to the terminal for 1 1/2 hours, seems necessary to achieve the following objectives :
- investigation of the pertinent parameters
- condition for movement
- model of sliding without friction.

Computing facilities :
Memory of about 3,000 words; language used, LSE. Alphanumeric consoles connected to a computer which has a compiler for LSE.

Stage of development :
This program has been used by about 30 pupils.

Further information :
Group "Informatique et Sciences Physiques" Mr. Hebenstreit, 12, Avenue Pierre Larousse, 92240 - MALAKOFF.

TITLE - ESCAPE

Source : Chelsea Science Simulation Project.

Materials : Student's Notes, Teacher's Notes and BASIC program.

Date of this outline : March 1974.

Subject and Specific Topic :
Physics. Escape velocity for object launched from earth.

Educational Aims :
To help students understand the idea of "escape velocity" (also to learn that greatest distance reached, escape velocity, etc. are independent of mass).

Advantages of the use of this material :
Although students may have heard of "escape velocity" many think that since the gravitational force ($1/R^2$) never becomes zero the object must eventually return to earth whatever its launch velocity. This program may help to convince students who cannot integrate $(1/R^2)dR$ that an escape velocity does exist (and that it is independent of mass).

Prerequisites on the part of the student :
Kinematics of constant acceleration, Newton's second law.

Student involvement
The problem (can an object be launched so fast that it will never return ?) is posed. Students can choose between three questions which the computer will answer :

a) Launch velocity needed to reach chosen distance ?
b) What velocity probe has left at certain distances ?
c) What is maximum distance travelled for chosen launch velocity ?

Student is directed by specific questions (is mass important ?; what velocity needed to get to distance of moon, sun, etc. ?)
A graph or table of launch velocity against distance (up to 10^{14}m) can also be obtained.

Time of involvement for an individual or small working group of students :
Total 1 hour, of which perhaps 1/2 at terminal.

Computing facilities :
Computer terminal connected to a computer providing interactive BASIC. 2100 words (of 16 bits) of working storage are needed.

Stage of development :
First draft material produced. Not tried with secondary school children.
First trials with secondary school children taking place.

Further information :
Computer Unit, Chelsea Centre for Science Education, (University of London), Bridges Place, London SW6 4HR.

TITLE - SCATTER

Source : Chelsea Science Simulation Project.

Materials : Student's Notes, Teacher's Notes and BASIC program.

Date of this outline : October 1973.

Subject and Specific Topic :
Physics. Scattering by hard objects and $1/R^2$ forces, scattering of alpha particles by metal foils.

Educational Aims :
To show students that one can learn about the nature (shape, size, etc.) of an object, from the way it scatters particles; to increase their understanding of the use of models in physics and to give some appreciation of the work of Rutherford, Geiger and Marsden.

Advantage of the use of this material :
Parts 1 and 2 (scattering by single objects) could be done with real equipment in lab., but would seem childish; the computer also allows more variety in objects used and "right" answer can be concealed. Part 3 (alpha scattering) cannot be done at school. In filmed experiment student cannot decide what parameters he wants to change. In all parts student is asked to respond to computer output, make judgements.

Prerequisites on the part of the student :
Law of reflection; inverse square law; transfer of energy (kinetic ⇌ potential) as particle moves in field; alpha particles.

Student involvement :
For each part some introductory reading plus questions to introduce the problems to be tackled at the computer terminal. Students will be asked to interpret "experimental" results by computer, and the last part to compare predictions of a simple model with experimental results provided.

Time of involvement for an individual or small working group of students :
2-3 hours total, of which probably less than 1 hour with access to computing facility.

Computing facilities :
Computer terminal connected to a computer providing interactive BASIC. The largest of the 3 programs requires 1800 words (16 bits) for execution.

Stage of development :
First draft material has been used by students in English secondary schools and colleges of education. Second draft materials available.

Further information :
Computer Unit, Chelsea Centre for Science Education, (University of London), Bridges Place, London SW6 4HR.

TITLE - FILING, FINDING AND LISTING

Source : Scottish Computer Education Group.

Materials : Name list, edge punched cards, data prep. forms, program.

Date of this outline : September 1974.

Subject and Specific Topic :
Business Studies. Secretarial studies - Retrieval of information.

Educational Aims :
To enable the pupil to establish a relationship between the conventional rules and methods of filing systems and at least one of the ways in which this can be done by computer.

Advantages of the use of this material :
"Hands-on" experience of a problem-based situation in filing data with a logical progression towards a solution of the problem.

Prerequisites on the part of the student :
a) Some knowledge of conventional filing methods (as introduced in O-grade Secretarial Studies).
b) A brief introductory knowledge of the computer.

Student involvement :
A group of pupils prepare a card for each name on a supplied list, and one or two conventional problems of card-index filing are presented. Holes previously punched in the card are then selectively opened up depending on the characteristics of the individual to whom the card refers and the "needle" method used to extract a set of cards having a chosen set of characteristics. The data is then transcribed to punched cards and the same data printed out on the reading of a parameter card containing a list of the chosen characteristics.

Time of involvement for an individual or small working group of students :
2 hours plus time to examine computer output.

Computer facilities :
Batch processing system with FORTRAN.

Stage of development :
This will eventually be integrated into a S.C.E.G. Secretarial Studies package.

Further information :
Contact : Scottish Computer Education Group, Jordanhill College of Education, 76 Southbrae Drive, Glasgow, Scotland.

TITLE - DATA PROCESSING SERVICE BUREAU

Source : Scottish Computer Education Group.

Materials : User's manual, data entry forms, program.

Date of this outline : September 1974.

Subject and Specific Topic :
Business Studies. Computerised accounting.

Educational Aims :
To each elementary accounting by the use of a model company.

Advantages of the use of this material :
The model company is a wholesale dealer in office equipment, and master files are set up at the start of the exercise. This provides a realistic background to the study of the various transactions and accounts.

Prerequisites on the part of the student :
Elementary book-keeping.

Student involvement :
The students, in one or more groups, act as employees of the model company. They may also act as customers and suppliers, or these roles may be played by the teacher.

Time of involvement for an individual or small working group of students :
3 1/2 hours minimum.

Computer facilities :
Batch Fortran IV with file handling facilities.

Stage of development :
Field tested version available.

Further information :
Contact : Scottish Computer Education Group, Jordanhill College of Education, 76 Southbrae Drive, Glasgow, Scotland.

TITLE - MAIL ORDER

Source : Scottish Computer Education Group.

Materials : Teacher's Manual, Operating Instructions, FORTRAN Program, Mail Order Catalogues or similar.

Date of this outline : August 1974.

Subject and Specific Topic :
Arithmetic/Business Studies. Interest, Credit Buying, Instalments.

Educational Aims :
Reinforcement of certain aspects of an arithmetic and/or business studies course by simulation of the well-known practice of Credit Purchasing by Mail Order.

Advantages of the use of this material over more traditional methods :
The use of the Computer as the Mail Order Firm injects realism into the project through the regular flow of material (using actual prices and interest rates) between customer (pupil) and firm (computer).

Prerequisites on the part of the student :
Interest calculations, Debit and Credit, ability to keep simple transaction records.

Student involvement :
Student acts as "supervisor" for up to 9 customers of the Mail Order Firm and makes payments and purchases on behalf of each - filling out the necessary forms and keeping transaction records.
The simulation operates at 3 levels of complexity.
1. 9 months' credit only.
2. Hire purchase and 9 months' credit.
3. Either or both of these plus Credit Card purchasing.

Time of involvement :
1/2 hour to 1 hour at any one time. Repeated at regular intervals for as long as required.

Computing facilities :
Card Reader, Printer, 8K Main Store, Disk File Capability.

Stage of development :
First version complete - Trials taking place in secondary schools.

Further information :
Contact : Scottish Computer Education Group, Jordanhill College of Education, 76 Southbrae Drive, Glasgow, Scotland.

TITLE - MULTI-PLOT

Source : Scottish Computer Education Group.

Materials : User's Manual, program.

Date of this outline : August 1974.

Subject and Specific Topic :
Mathematics. Produces on the line printer up to 5 curves on one set of axes, each curve representing a single valued function of the form $y = f(x)$.

Educational Aims :
To enable the student to explore the graphical results of varying parameters within the function $f(x)$.

Advantages of the use of this material :
The generation of families of curves without the help of a computer is usually so laborious that it is seldom undertaken on an exploratory basis.

Prerequisites on the part of the student :
Some experience of graph drawing and elementary algebra.

Student involvement :
The teacher might ask the student to investigate the effects of variations in a particular parameter. The student would then run the package several times over different ranges of the variable and produce a report on his findings.

Time of involvement for an individual or small working group of students :
1 - 2 hours.

Computer facilities :
Batch Fortran IV with line printer.

Stage of development :
Batch version available. An interactive version is under consideration.

Further information :
Contact : Scottish Computer Education Group, Jordanhill College of Education, 76 Southbrae Drive, Glasgow, Scotland.

TITLE - CHOROMAP

Source : Scottish Computer Education Group.

Materials : User's Manual, pre-printed tracing paper, Fortran program.

Date of this outline : August 1974.

Subject and Specific Topic :
Geography. Production of choropleth maps from raw data. The maps are produced on the computer line printer.

Educational Aims :
To provide pictorial representations of statistical data which would be less comprehensible as a table of figures.

Advantages of the use of this material :
Maps can be produced which display data which is too recent or too detailed to appear in published atlases. It is most useful where a series of maps is required displaying various statistics over a particular area.

Prerequisites on the part of the student :
An elementary understanding of maps, and the graphing of numerical data into bands.

Student involvement :
Group activities will involve the preparation of the data for the map outline and the collection of numerical data either by search of published sources or directly in the field. A wide range of data types may be used depending on the course being taught.

Time of involvement for an individual or small working group of students :
Minimum 1 hour but could be much more.

Computer facilities :
Batch Fortran IV with line printer for output.

Stage of development :
Fully developed. A second version is available which takes map outlines from a library stored on disk.

Further information :
Contact : Scottish Computer Education Group, Jordanhill College of Education, 76 Southbrae Drive, Glasgow, Scotland.

TITLE - PCRA (Comparative Regional Analysis)

Source : Scottish Computer Education Group.

Materials : User's Manual, Fortran program.

Date of this outline : September 1974.

Subject and Specific Topic :
Geography. Provides a statistical comparison between data from a number of regions. The analysis can be at various levels from national to parish.

Educational Aims :
To show how various useful comparisons can be made from statistical data.

Advantages of the use of this material :
Without the aid of a computer comparisons of this kind might be discussed but never actually carried out because of the volume of data and calculation involved.

Prerequisites on the part of the student :
An understanding of the sources and significance of the data to be processed.

Student involvement :
Data collection and preparation. Discussion of the significance of the results.

Time of involvement for an individual or small working group of students :
5 - 6 hours including preparatory teaching.

Computing facilities :
Batch Fortran IV with sizeable core, or backing store.

Stage of development :
Working version available.

Further information :
Contact : Scottish Computer Education Group, Jordanhill College of Education, 76 Southbrae Drive, Glasgow, Scotland.

TITLE - PNETD (Transport Network Analysis)

Source : Scottish Computer Education Group.

Materials : User's Manual, Fortran program.

Date of this outline : September 1974.

Subject and Specific Topic :
Geography. Computation of distances and detour indices for a network of communications.

Educational Aims :
To help with the teaching of regional communications analysis.

Advantages of the use of this material :
By undertaking tedious arithmetical calculations the program allows the consideration of a substantially larger number of nodes and links than would normally be tackled in school work, thus allowing more realistic studies to be undertaken.

Prerequisites on the part of the student :
The ability to extract the necessary data from maps.

Student involvement :
Preparation of data for the computer, discussion of the results.

Time of involvement for an individual or small working group of students :
5 - 6 hours, including preparatory teaching.

Computing facilities :
Batch Fortran IV with sizeable core or backing store.

Stage of development :
Working version available.

Further information :
Contact : Scottish Computer Education Group, Jordanhill College of Education, 76 Southbrae Drive, Glasgow, Scotland.